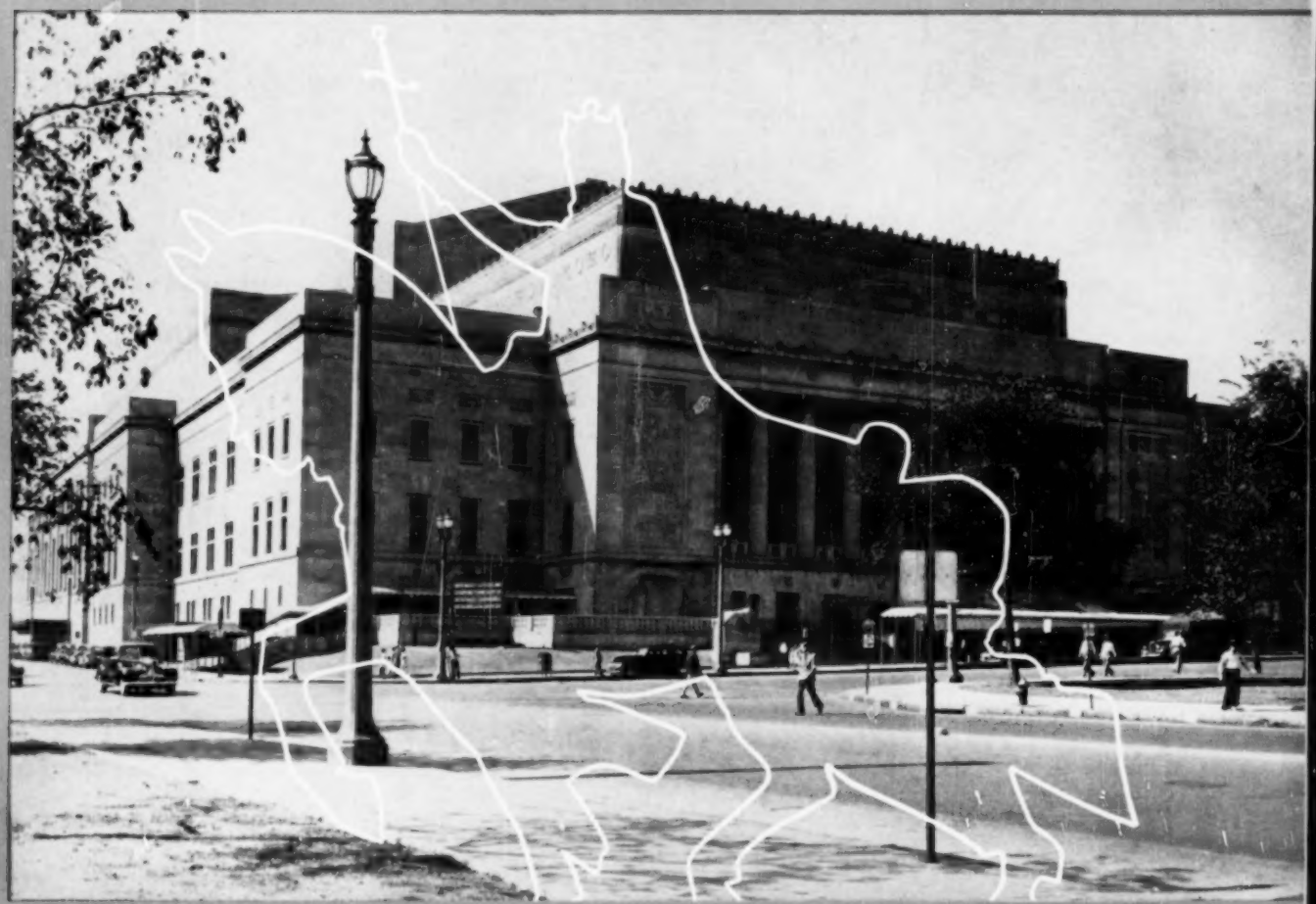
Industrial QUALITY CONTROL

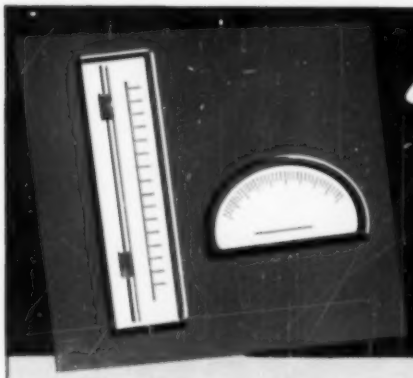
MAY, 1954 Vol. X No. 6

EIGHTH ANNUAL CONVENTION



Kiel Auditorium — St. Louis, Mo.

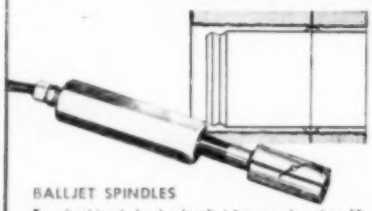
AMERICAN SOCIETY FOR QUALITY CONTROL



Modernize FOR LOW COST PRODUCTION with Newest Developments In Air Gaging

Already these newly developed practical precision tools are helping produce more and better products at lower cost in innumerable plants throughout the world.

Space restrictions here preclude anything more than the briefest description. Phone, wire or write for specifications, prices and delivery—or call the Sheffield sales engineer in your vicinity.



BALLJET SPINDLES

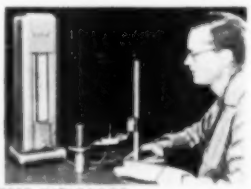
For checking holes having finishes rougher than 65 micro-inches, for porous parts, narrow lands or checking to the very end of a hole. Setting is made with gage blocks and a Standard Calibrator. NO MASTER SETTING RINGS REQUIRED—not even one.

ADJUSTABLE SPINDLE KIT

One, two, three or four spindles may be quickly assembled from components in the kit, for any size between 1 and 3 inches. Gage blocks are used to set for size and to calibrate air gage for amplification.

ADJUSTABLE AIR BORE GAGE

A light, high precision (2,000 to 1 amplification) self-centering bore gage that is easily adjustable from 3" to 12" in diameter. Calibrated by a Standard Calibrator and gage blocks.



AIRETEST INDICATOR

Replaces an indicator where more accuracy and higher amplification are required. Always gives precise readings regardless of the direction of approach. No lag—no gears—nothing to wear out of adjustment. Amplifications up to 5,000 to 1.

AIRELECTRIC HEAD

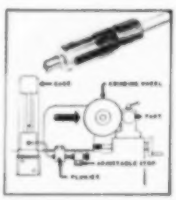
Converts air pressure variations at the gaging contact into electrical impulses which actuate classification and segregation mechanisms or machine control devices. Accurate to a fraction of a "tenth".

ELECTRO-PNEUMATIC UNIT

A self-contained unit of Airelectric Head, indicating dial and signal lights. Easily mounted on the machine to control machine operation by precision measurement of the machined surface. Makes machining automatic. Also used for automatic gaging and segregating.

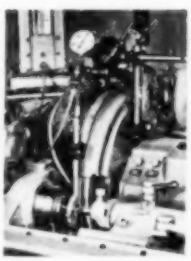
PLUNJET FEED GAGE

The key element of the machine "Feed Gage" which eliminates error due to feed screw wear. Also, due to the high amplification, makes it easy to manually control the feed to fractional "tenths"



PLUNJET CALIPER TYPE GAGE

Air Gaging Cartridges are used with Caliper Gages for continuous sizing of work on external grinders. Dial is used for approach —PLUNJET brings to final size.



PLUNJET GAGING CARTRIDGES

Precise, low-cost gaging elements which you may incorporate in your own gaging fixtures singly or in multiple to measure practically any dimension or geometrical relationship, with tolerances ranging from .0005 to .100.

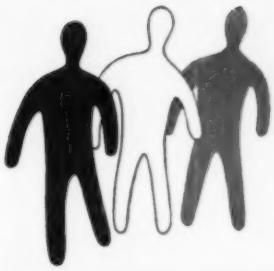
GAGE DIVISION, *The Sheffield Corporation*
Dayton 1, Ohio, U.S.A.

6756

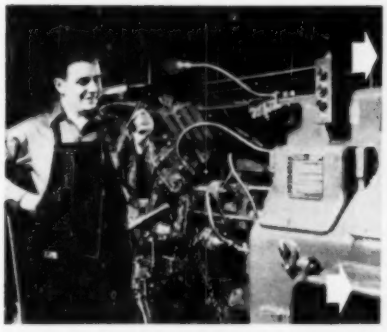
MASTER CRAFTSMAN SHEFFIELD HEADQUARTERS

SHEFFIELD

PHONE, WIRE OR WRITE



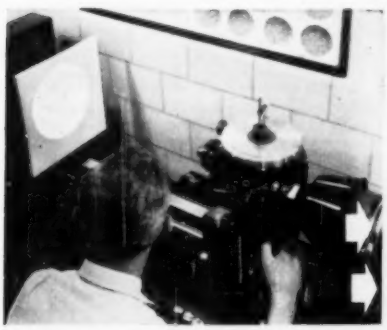
HERE'S WHAT HAPPENS WHEN REPUBLIC'S 3-D METALLURGICAL SERVICE GOES INTO ACTION



The field metallurgist comes right into your plant. He checks furnace temperatures and heating cycles, machines, set-ups, feeds, speeds, everything which affects your production.

He talks to your plant and engineering people, asks questions, finds out what you want your alloy steels to do. He takes this data with him.

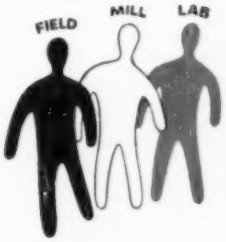
The Republic Field Metallurgist talks over his report with Republic's Mill Metallurgist. Experienced in producing alloy steels, he adds his knowledge, checks it against your problem. And since Republic controls its alloy steels from ore to finished product, he can trace heats of steel.



The field metallurgist next talks things over with the Republic Laboratory Metallurgist. His data on tests of alloy steels is added to the material of the field and mill metallurgist.

Then, all three men put their heads together and come up with a recommendation that is the result of pooling their findings and their experience with alloy steels. And since Republic pioneered the manufacture of alloy steels, this recommendation is based on solid data.

The Republic Field Metallurgist passes this recommendation on to your engineers and plant personnel. He works with them to see that your problem is solved satisfactorily, right in your plant. It's his job to see that you get all the advantages out of the alloy steels you use.



The results often include lower production costs, better quality, or even changes in design. You can have this free service by calling your local Republic Steel sales office.

REPUBLIC STEEL CORPORATION
Alloy Steel Division • Massillon, Ohio
GENERAL OFFICES • CLEVELAND 1, OHIO
Export Dept.: Chrysler Bldg., New York 17, N.Y.

REPUBLIC STEEL

Republic ALLOY STEELS

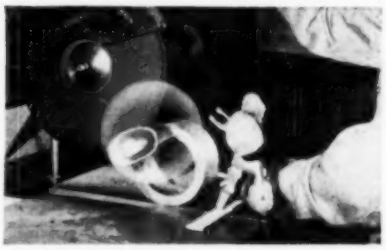
Other Republic Products Include Carbon and Stainless Steels—Sheets, Strip, Plates, Pipe, Bars, Wire, Pig Iron, Bolts and Nuts, Tubing.

The BD is the preferred hub-type wheel for heavier stock removal. Ideal for smoothing and blending welds on fabricated work; smoothing flame-cut edges and stainless steel welds, cleaning between teeth of gear castings; many slotting, notching and cutting-off operations.

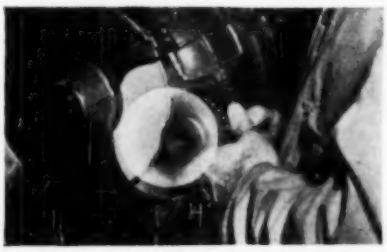
The BFR is outstanding for light snagging, light weld grinding, smooth finishing, blending contours and corners, removing mold marks, removing rust and scale, and scarfing and beveling before welding. Also for notching gates and risers.

4 Great Team-Mates for your "TOUCH of GOLD"

Norton REINFORCED WHEELS add value, cut costs on hundreds of grinding jobs



The BN is the recommended cut-off wheel wherever great strength and safety are vital. Excels at cutting-off non-ferrous gates and risers and various non-metals. Its range also includes cutting wire rope, slotting rails, tuck pointing, etc. Small sizes are popular on small portable grinders.



The BF, a straight wheel version of the BFR, is the wheel to use for light deburring, breaking edges on machined work, taking off flash from plastic parts, removing light welds and many other miscellaneous light portable and bench grinding applications.

BF Mounted Wheels and Points, like all Norton mounted wheels and points, are trued on their own spindles. Having the same laminated construction as the larger BF wheels, they are designed for such jobs as finishing plastic molds, glass molds, forging dies, etc. For hand finishing, use BF sticks.

Here's the Line-Up

BD Rigid hub-type, resinoid bonded. Glass cloth reinforcement for high strength plus the Nylon layer add up to extra hub-wheel safety. For the more severe jobs on your right angle grinders.

BFR Semi-flexible hub-type, resinoid bonded. Cotton fabric reinforcement with the additional layer of Nylon. For better finish and contour blending.

BF Semi-flexible straight wheel, resinoid bonded. Cotton fabric construction similar to the BFR but without Nylon reinforcement. For periphery grinding only. An excellent deburring and finishing wheel. Also available in mounted wheels and points and in hand sticks.

BN Straight wheel, resinoid bonded. Glass cloth reinforcement, as in the BD. Provides very high resistance to breakage in a wide range of cutting-off and other jobs.

Add outstanding versatility to strength and to safety, multiply the result by four and you have one reason why this Norton team rates as the "Big 4" among reinforced wheels.

Separately, each handles a considerable number of important grinding jobs. Together, they cover an almost endless list of applications, ranging from light deburring to severe cutting-off. And they do every one of these jobs with the *extra* safety, service life and economy that add the real "Touch of Gold" to your grinding operations.

Quality Control

is an important reason for the superiority of Norton reinforced wheels. From the moment that the abrasives, bonds and other raw materials enter the mile-long Norton Worcester plant until the completed grinding wheels are shipped, quality control plays an important part in their manufacture. Norton Company, Worcester 6, Mass. Warehouses in Five Industrial Centers — Distributors in All Principal Cities.

W-1553A

NORTON
ABRASIVES

Making better products... to make other products better

Be Sure To Vote!

Either just before or just after you receive this issue of IQC, you will also be receiving your ballot to vote for our Society officers for next year and for certain proposed constitutional amendments. In addition you will receive a similar important proposed amendment to the articles of incorporation. A proxy will also be included in the material you receive and this proxy must be signed by you in order that the executive secretary will have the authority to cast your ballot on amending the articles of incorporation.

In essence, the amendments propose a deletion in the ASQC constitution and articles of incorporation. This change is vital from a legal standpoint to qualify ASQC as an incorporated, nonprofit, educational and scientific organization. The law on several occasions has read into our articles of incorporation, as now worded, an implication that ASQC is a fraternal organization. This interpretation restricts your officers from putting the Society in a position to enjoy certain important legal privileges that will become available if the proposed amendments are approved.

Please cooperate by reading these proposals carefully when you receive them and sending in both your ballot and proxy on them. We must have at least 50 percent of the entire membership vote on the articles of incorporation in order to make the voting valid.

You will notice that in addition to the ballot and proxy there are two envelopes, as usual. The ballot for the officers and the constitutional amendments should be marked, placed in the small plain envelope, and the envelope sealed, again as usual. The proxy, however, has to be signed by you in order to be valid. Therefore, the signed proxy and the sealed envelope containing your ballot should be placed separately in the large envelope for mailing back to our headquarters office at New York. Do *not* put your signed proxy into the small envelope containing the ballot, because the ballots are secret and are not opened until the annual meeting at the Convention.

But, *be sure to vote.* When you receive your ballot and proxy, look them over, decide how you want to vote, and then do so right away. Don't run the risk of mislaying them or forgetting about them by setting them aside to think about later. And remember, for the vote on the articles of incorporation to be valid 50 percent of our entire membership must either send in signed proxies or vote in person at the annual meeting. Our membership as of April 1 is already over 8000. Last year with 7000 members, less than ⅓ cast ballots. So let's all vote—each and every one of us. Let's not depend on someone else to make our decision and have it go by default.

Industrial Quality Control

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Membership in the Society is personal and professional, and is not open to corporations, companies, or other organizations.

Contributions to the Society from corporations, companies, and others for the support of its activities are welcomed and appreciated.

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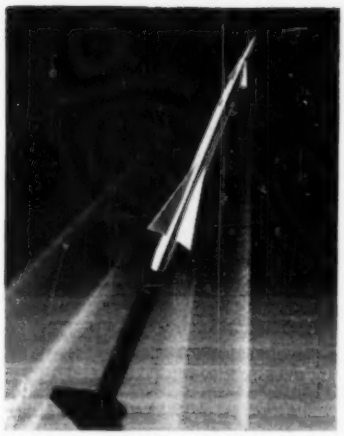
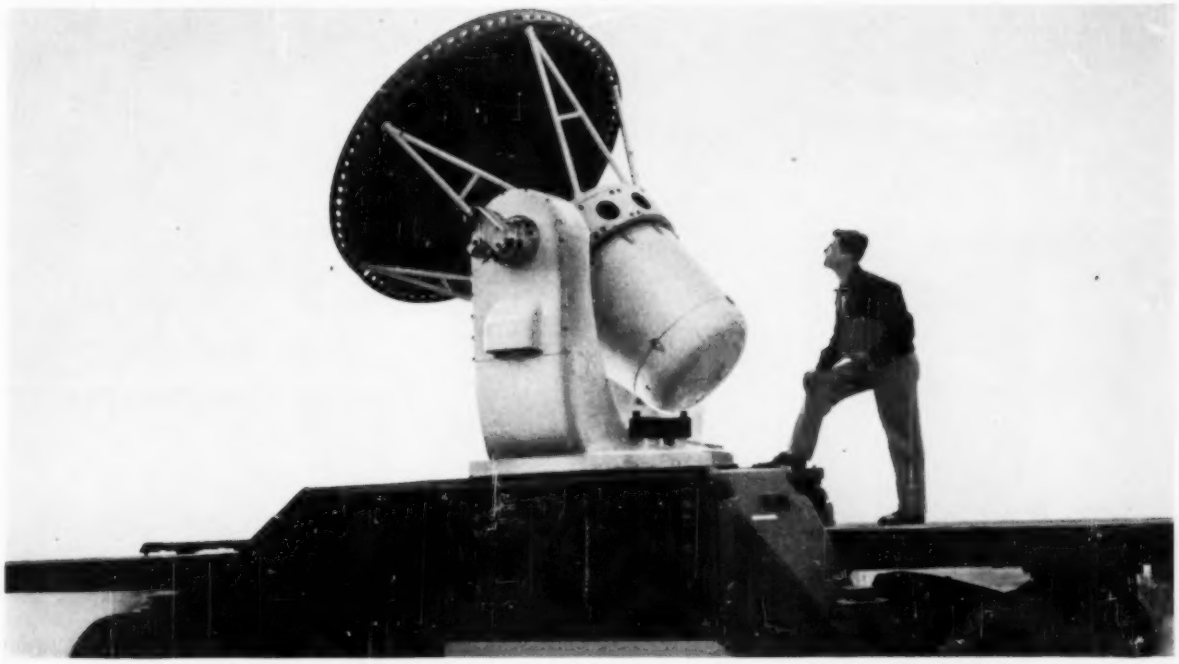
INDUSTRIAL QUALITY CONTROL
Advertising space is available



TELEPHONE SCIENCE GUIDES A PUNCH NO ENEMY CAN DODGE



(Upper left) – Nike's missile climbs to destroy an enemy, under guidance of complex electronic controls. A radar is shown at right. Nike (pronounced Ny'kee) is named after the Greek goddess of Victory.

BELL TELEPHONE LABORATORIES

Is it possible to guide an anti-aircraft missile so that it will track down and destroy a rapidly maneuvering target? No one knew the answer for sure when the U. S. Army put this question to Bell Telephone Laboratories in 1945.

The special skills and techniques developed to create the nation's communications network uniquely fitted Bell scientists to answer this question. They recommended a new system, Nike, and then worked to bring it into being with engineers from Army Ordnance, Western Electric Company and Douglas Aircraft Company.

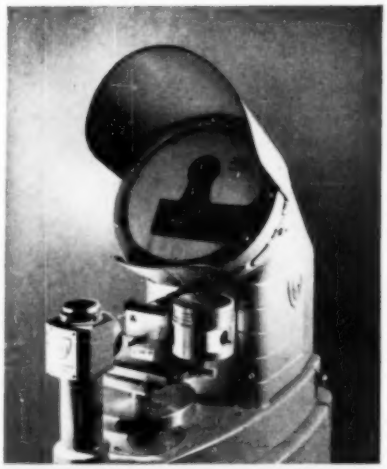
The first Nike installation has been made, and more will follow. Thus, America's defenses grow stronger through a new extension of frontiers in the communications art. It is a proud achievement of the knowledge and skills first developed at Bell Telephone Laboratories to make the nation's telephone service ever better.

Improving telephone service for America provides careers for creative men in scientific and technical fields

Are you overlooking the versatility of optical gaging?

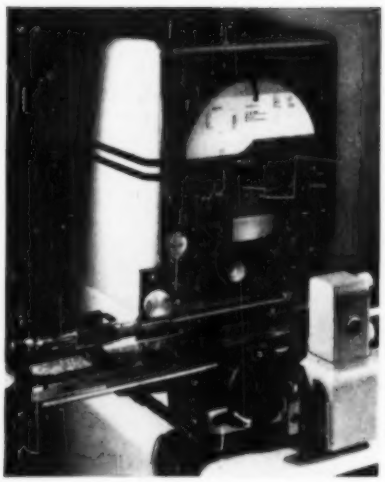
VISIT US AT
BOOTHS 21 and 22

If you have been thinking of optical gaging only in terms of shadow projection, you may be missing an opportunity to lower your inspection costs, speed the work. By modern optical gaging techniques, you can inspect:



LARGE PARTS

A tracer is used to transfer related points on this large piston within the limits of the comparator screen.

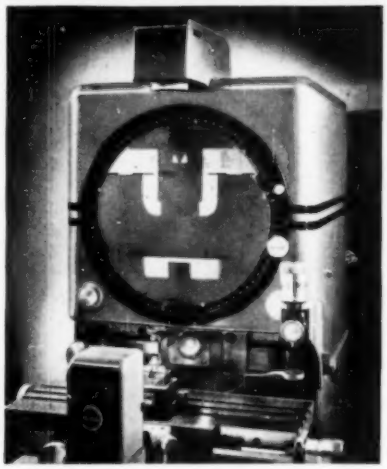


LONG PARTS

An accurate index bar positions various shoulders of 27″ long drive shaft for checking 22 critical dimensions.

DIMENSIONS YOU CAN'T SEE

A double target plunger is used to check 4 dimensions on this gun part that can't actually be projected.



Fast, accurate, and economical, optical gaging may well be adaptable to your quality control requirements. We welcome the opportunity to show you how. Just send us your part specifications with critical dimensions indicated for our analysis.

OPTICAL GAGING PRODUCTS INC.

26 FORBES STREET, ROCHESTER 11, N. Y.

SPECIALISTS IN PROJECTION GAGING

INDUSTRIAL QUALITY CONTROL

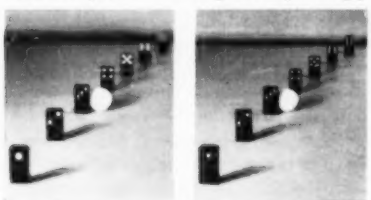
Plain Pointers on Projection

ONE of the claims we make concerning the Kodak Contour Projector is that once an object is brought into focus at any given magnification it will remain in focus when magnification is changed. (This freedom to change magnification is made possible through the use of a lens turret, mounting six lenses, and speeds inspection procedures.) An operator only need flick a dial to switch from one magnification to another: no time is lost refocusing.

Occasionally, however, one of our customers writes to question our claim and declares that he has found it necessary to refocus when changing magnification. This does not upset us. Almost invariably the difficulty can be traced to the phenomenon of optics called "depth of field." This refers to the distance between the nearest and farthest points sharply defined by a lens and is aptly illustrated by the picture below. It is apparent that when a lens is focused on one object, other objects—nearer and farther from the lens—may appear in acceptable focus.

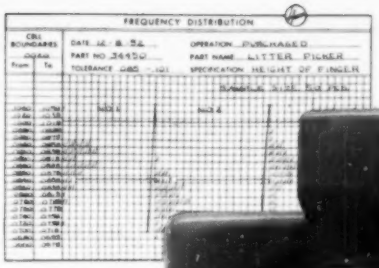
One of the characteristics of this phenomenon of depth of field is that it decreases sharply as magnification is increased. This is equally true when a lens is focused on an actual object, as with a camera, or on an image of that object, as is the case with our contour projector. The result is that when working at higher magnifications depth of field is considerably less than when working at lower powers.

Consequently, it is possible that an object in focus at 10 power may appear out of focus when magnification is changed to 100 power, where depth of field is less and the need for precise focusing correspondingly

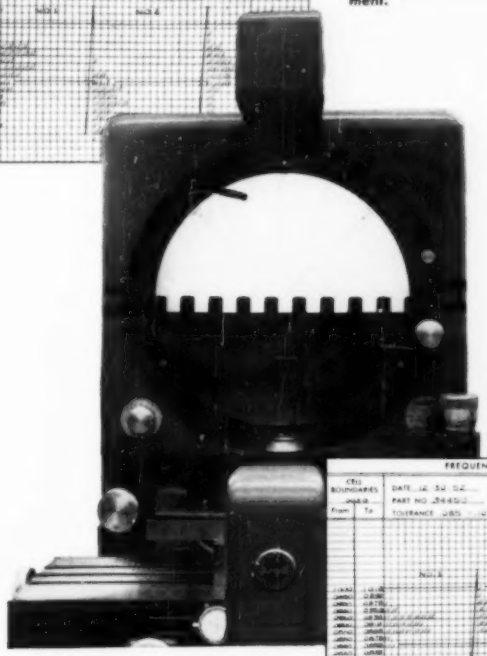


greater. Because of this, we recommend that, when inspecting parts at several magnifications, the part first be focused at the highest magnification to be used. This insures focusing within the narrowest tolerances and, when magnification is changed to a lower power, the part remains in sharp focus on the screen. When this recommendation is followed, complaints on the need for refocusing vanish.

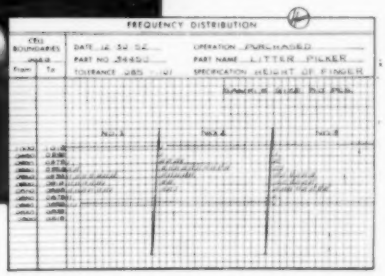
Incidentally, it should be mentioned that neither focus nor depth of field affects accuracy of magnification with the Kodak Contour Projector. This remains as rated irrespective of the precision of focus, thanks to what our optical people call a telecentric stop. Which, in itself, is subject for another in this series of columns.



Frequency distribution chart of part size based on optical measurement.



Frequency distribution chart of part size after tool alterations.



Saved...296 pieces per thousand!

Like many another manufacturer, the Hoover Company, Canton, Ohio, has its rejection problems. A typical one involved a flexible, rubber-like "litter picker" used in its vacuum cleaners. Although tolerances ranged from .085" to .101", rejects ran as high as 30%.

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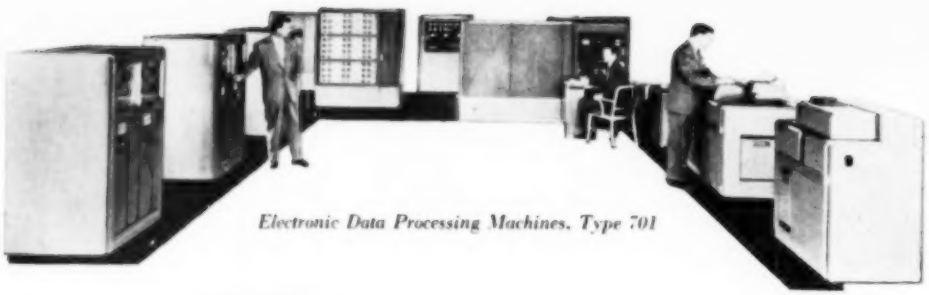
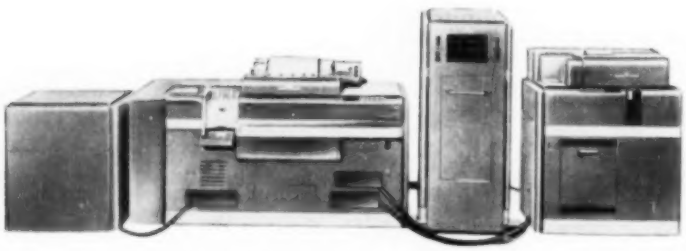
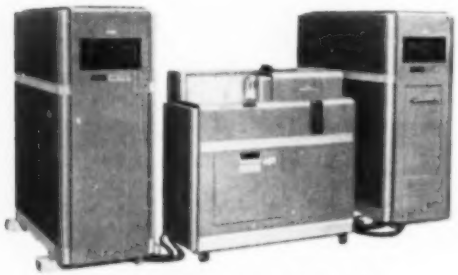


Electronic Data Processing Machines, Type 701

IBM's new Type 650, a magnetic drum machine



Card-programmed Electronic Calculator



Electronic Calculator, Type 607

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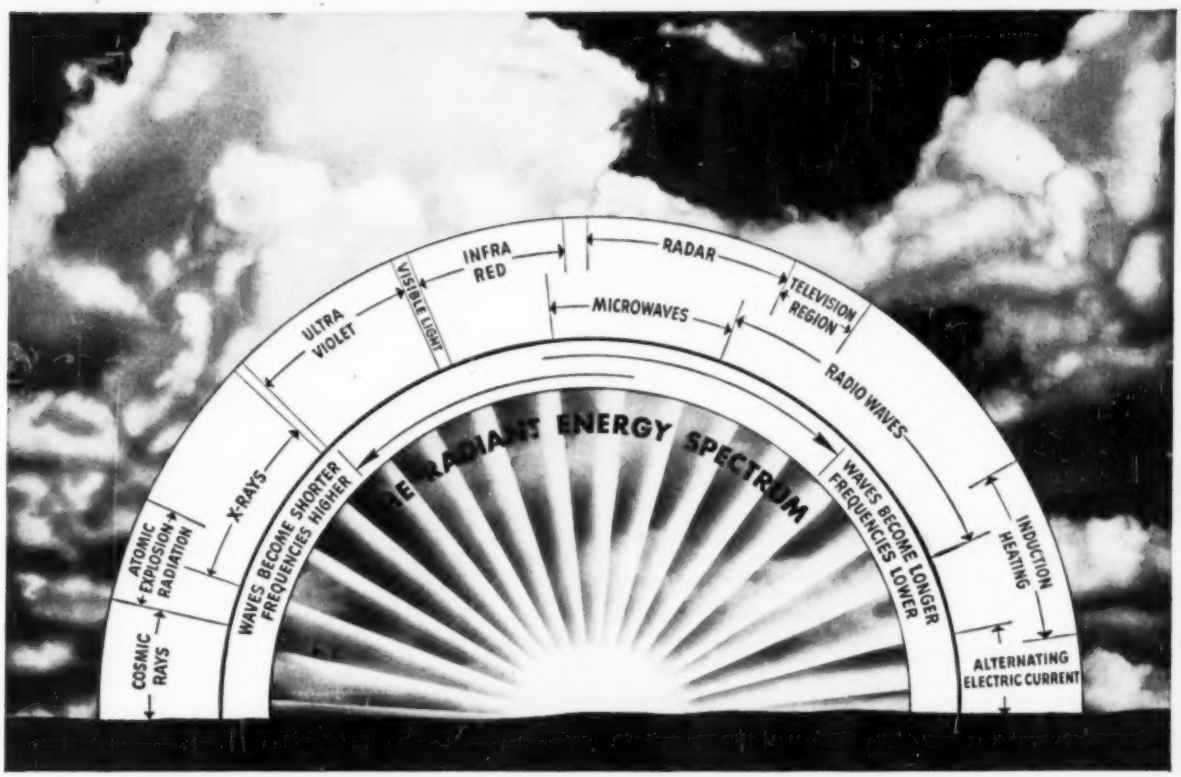

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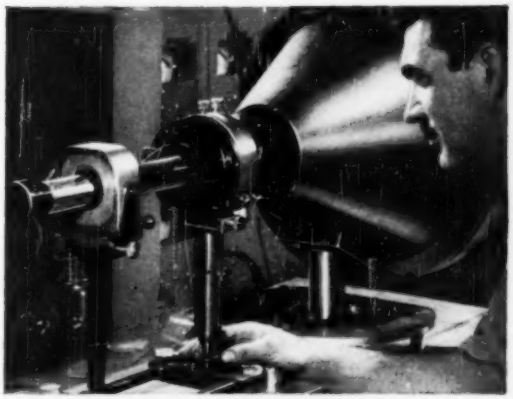
The research and development under way at Sylvania's laboratories reaches, in some way, into virtually every phase of this spectrum. In the broad fields of *lighting, radio, electronics, television,* Sylvania engineers are constantly developing new techniques, finding new knowledge—*to meet the future needs of home and industry.*



Television is one of the major research projects under way at Sylvania's Research Center, Bayside, L. I., New York.

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Along with aircraft engines Allison also designs and builds Allison Torqmatic Drives. In the space of a few short years, Allison has become the world's largest manufacturer of Torqmatic Drives for use in Ordnance and commercial vehicles and equipment. Down in Venezuela, for instance, in the Maracaibo Lake region, Torqmatic Drives built by Allison are used on oil drilling projects. And, on the big building projects like the Ft. Randall Dam in South Dakota, you'll find the heavy duty trucks and big earth moving equipment are equipped with Allison Torqmatic Drives.

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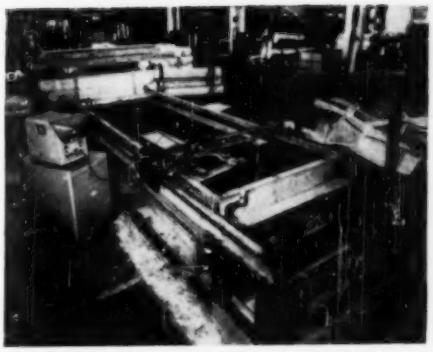

Using an oscilloscope to indicate the amplitude and position of reflected high-frequency signals that have been sent into the immersed forging, skilled operators can evaluate its structural soundness. Reflected wave patterns provide assurance of internal soundness with a degree of accuracy not available before the advent of ultrasonic inspection.

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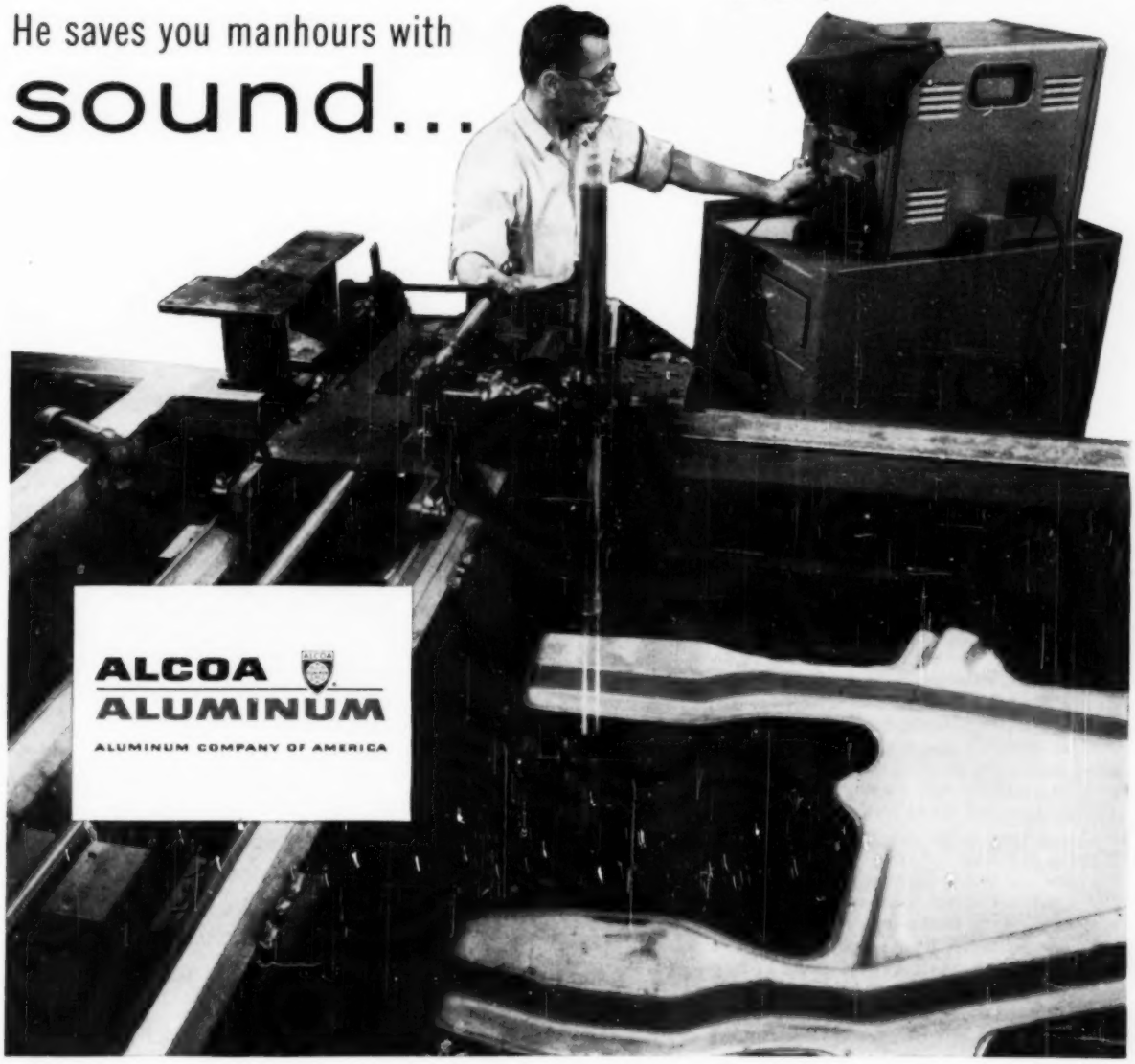

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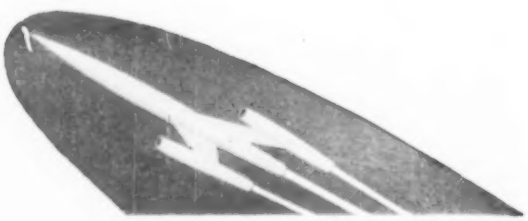

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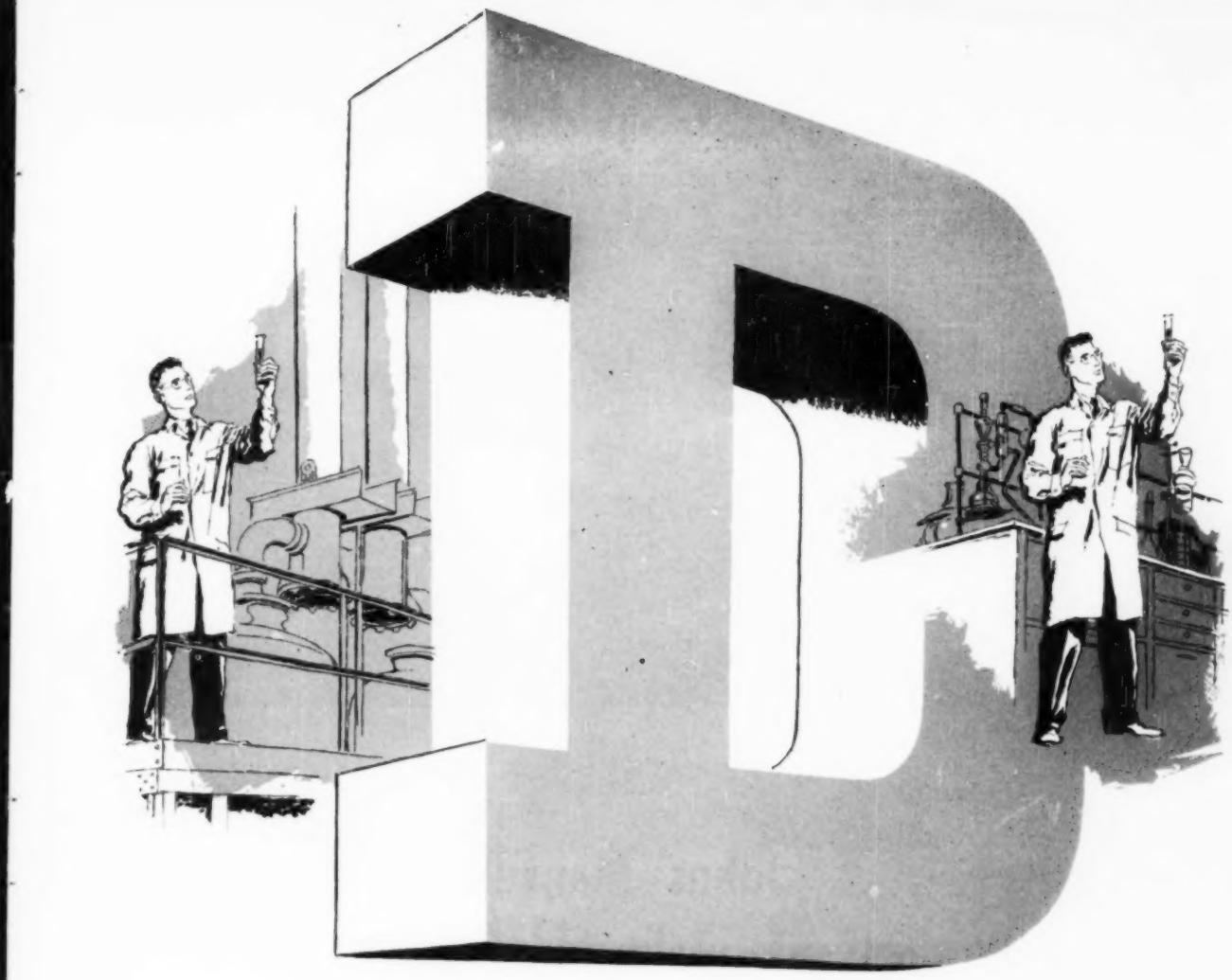

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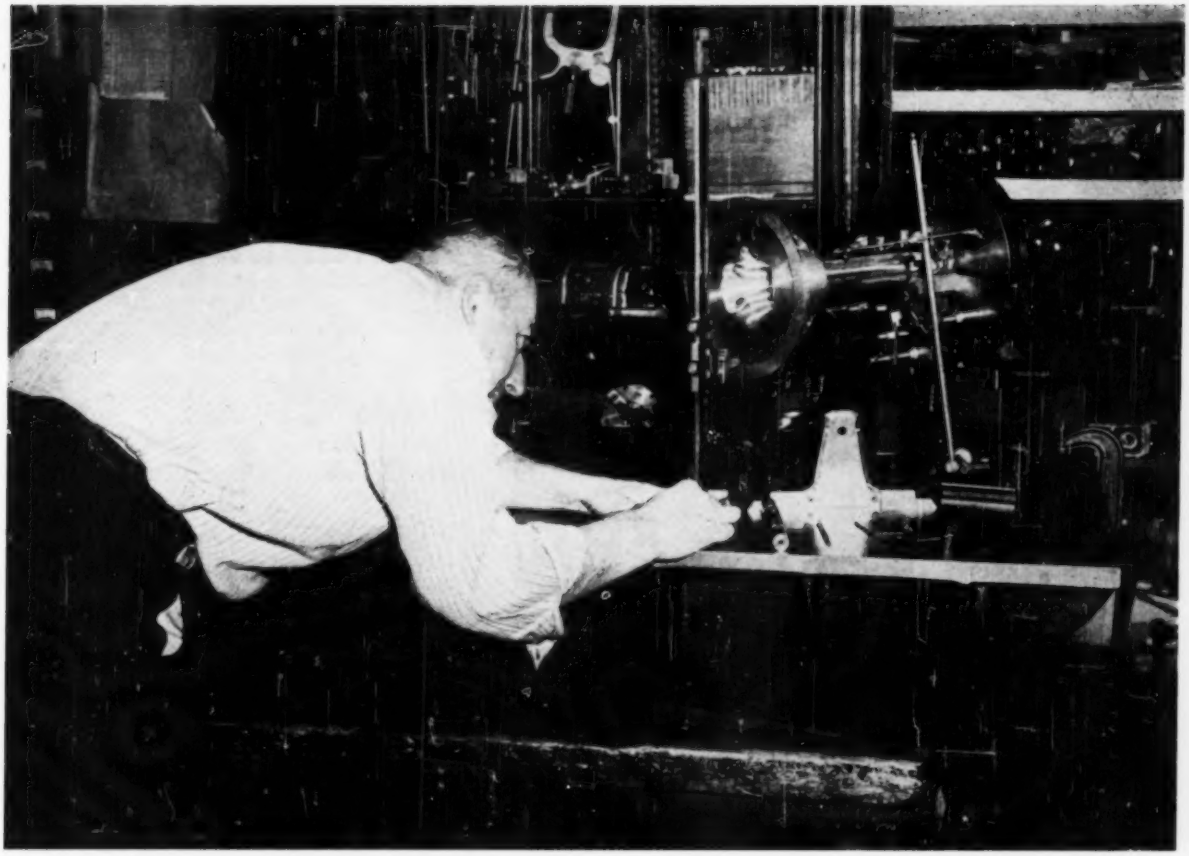

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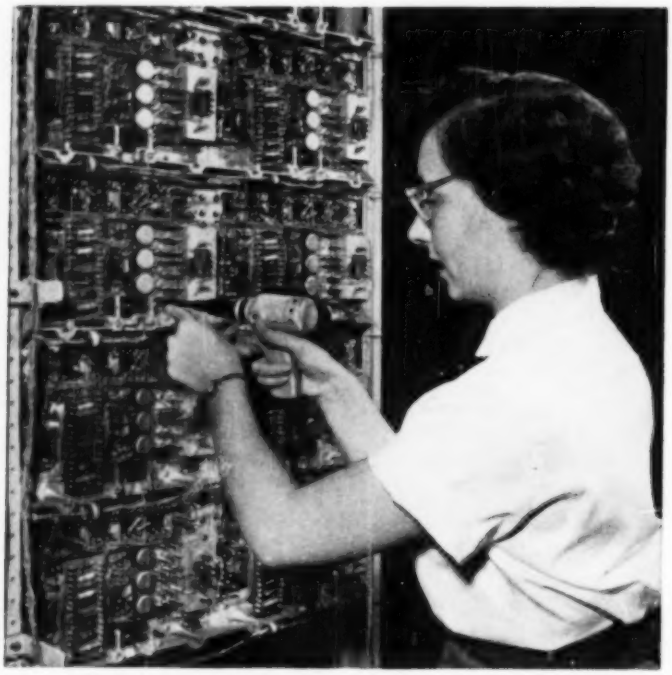
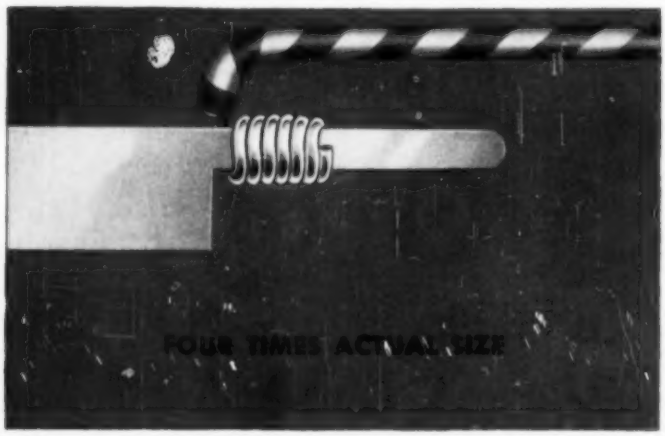
An Example of Quality Control Applied to Production Tool Performance



New manufacturing tool presents an opportunity for quality control applied to production tool performance.



Closeup shows solderless connection made with pistol-like power tool shown in use above.

Recently, a pistol-like power tool capable of making mechanically sound solderless wire connections was developed by Western Electric and its teammate, Bell Laboratories. Introduced into Western Electric production lines, this revolutionary advance in manufacturing techniques presents an opportunity for process quality control impossible with ordinary soldered connections.

Here's why: Soldering is a manual operation and the quality of the connections can be effectively determined only by actual examination of the connections. With use of the new "wire-wrap" tool, however, the human-error factor is minimized. Now, the major factors which control the quality of connections are the tightness and evenness with which the automatic tools wrap the wires around the terminals, and application of Statistical Quality Control techniques, including tests made of each tool before use and at frequent intervals during use, provide continuing assurance that only good connections are being made.

This is another example of how Western Electric is constantly applying quality controls to manufacturing processes to maintain and improve quality of Bell telephone equipment.

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Statistical Techniques for Managerial Control*

HOWARD L. JONES

Illinois Bell Telephone Co., Chicago, Ill.

INTRODUCTION

The control of large business operations requires management people at all levels to keep and interpret performance indexes of many kinds. Examples of such indexes are volume of sales in dollars or other units of measurement, profit margin per dollar of sales, number of customer complaints, number of work units produced per employee hour, number or percent of defective units, and number of days lost by employees on account of sickness or accident. More elaborate indexes computed by various weighting procedures are common.

The purpose here is to describe an approach to interpreting one of these indexes. This approach leads to objective answers to questions as to whether the position of the index indicates the need for investigation with a view to possible managerial action. It is being used successfully by hundreds of management people throughout the United States and in several foreign countries. While experience has been most extensive in the quality control of manufactured products, the same principles are applicable in other fields.

For illustrative purposes, the index discussed is assumed to measure some kind of performance at a division level. But the discussion also applies to indexes at the company level, and on down to indexes measuring the performance of an individual worker.

THE PROBLEM

Joe Smith is division manager for X Corporation (Fig. 1). On the wall behind him is a chart showing the recent behavior of a performance index for Joe's division.

Yesterday's figure has just been plotted on this chart. It's two points below the previous figure. The question immediately arises:

IS THIS DROP IN PERFORMANCE SIGNIFICANT?

Knowing the right answer to this question is important. If the drop is significant, Joe should do something about it. He ought to find out what caused the drop, and take steps to bring about improvement. On the other hand, as Joe well knows, there are always some fluctuations up and down that don't mean anything. If Joe investigates every little fluctuation and tries to do something about it, he will be wasting his time and the time of several other people who are trying to help him. Looking for trouble that does not exist can be very expensive.

Fortunately, Joe doesn't have to guess about the right answer. He knows immediately whether he should investigate. How he knows is outlined next.

THE CONTROL CHART

A close look at the chart (Fig. 2) reveals some broken horizontal lines. Joe calls the upper line the *upper control limit*. The lower one is called the *lower control limit*. As long as the index stays within these limits, Joe doesn't need to worry. The fluctuations within this band don't mean very much. But if the index gets below the lower control limit, something is slipping. Joe had better find out why, and do it right away. On the other hand, if the index goes above the upper control limit, it calls for a celebration. A performance that good is no accident. Something new has brought about a real improvement. Joe had better see what this new thing is, and try to make the improvement permanent.

A chart of this kind, with upper and lower control limits, is known as a *control chart*. It does two things for Joe. First, it shows him how his index compares with a *standard index* of performance, plotted as a heavy horizontal line midway between the control limits. Second, it shows him whether the difference between his index and the standard index is great enough to be of any significance. The interpreting procedure is quick and sure. All Joe has to do is glance at the chart.

The trick, of course, is to design the control chart so that it will actually distinguish between fluctuations that are significant and those that are not. This trick is briefly described in what follows.

INTERPRETING FLUCTUATIONS

The proper design of a control chart rests on a very important principle: If the fluctuations in any index are due to the combination of a large number of small

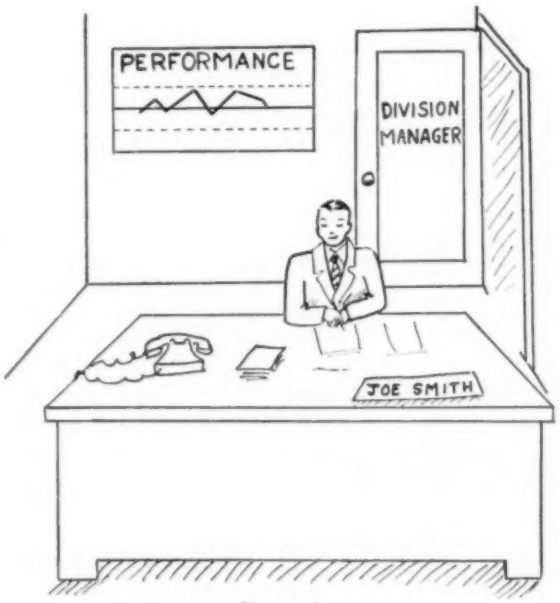


Figure 1

*Presented as part of a talk at the Sixth Midwest Quality Control Conference, Chicago, Ill., November, 1951, and later as part of a paper presented at the Sixth National Convention, ASQC, Syracuse, N. Y., May 1952.

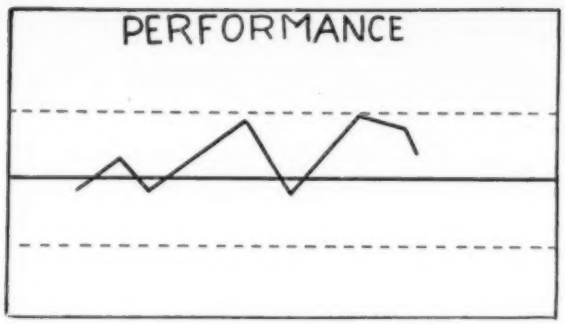


Figure 2

chance causes, then these fluctuations will have a definite pattern, as shown by the diagram in Fig. 3. From this pattern, known as the normal distribution, a statistician can predict the relative number of times the index will fall between any two given values. In particular, he can compute two values outside which the index will practically never fall, and set these two values as the control limits. If the index ever does fall outside these limits, he can be pretty sure that some new, important cause of fluctuations has entered the picture.

Joe Smith can make good use of this principle. As long as the fluctuations in his index are due to the combination of a large number of small chance causes, it will usually not be economical for him to investigate any given fluctuation, since the effect on the index of eliminating one or two causes would be too small to make the investigation worth the cost. On the other hand, when the fluctuations are assignable to one or two important causes, it will nearly always pay to investigate.

A properly designed control chart automatically sorts out the fluctuations between those due to important big causes and those due to unimportant little causes. That's the reason the chart is so useful.

DETERMINING STANDARD PERFORMANCE

The first step in designing a control chart for Joe consists in analyzing historical data as to actual performance to see whether the indexes follow the bell-shaped normal distribution (Fig. 4). If so, the average of the indexes can be established as the standard performance level, and control limits can be computed by methods described in the textbooks on statistics and quality control. All the indexes used in making the computations will lie within these limits, and the performance is said to be in *statistical control.*

If some of the indexes used in the computations fall outside the control limits as initially determined, there are important assignable causes of fluctuation present. In that case, the computations should be repeated after excluding the indexes outside the initial limits. Further repetition may be necessary before all the indexes used in the computations will lie inside the revised control limits. The last revision will result in a tentative control chart that will be suitable for a time in helping Joe make decisions as to when action is necessary. The final revision must wait until Joe has eliminated those important causes of fluctuation.

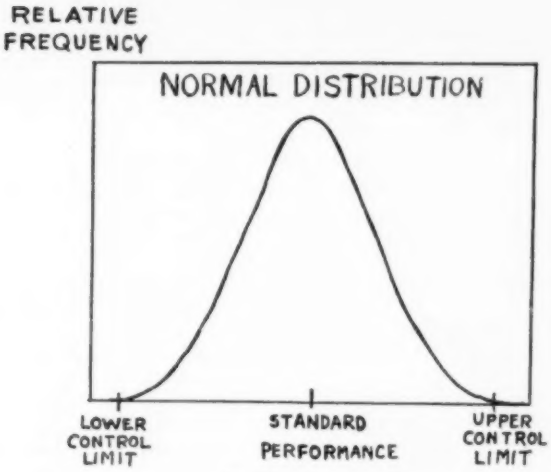


Figure 3

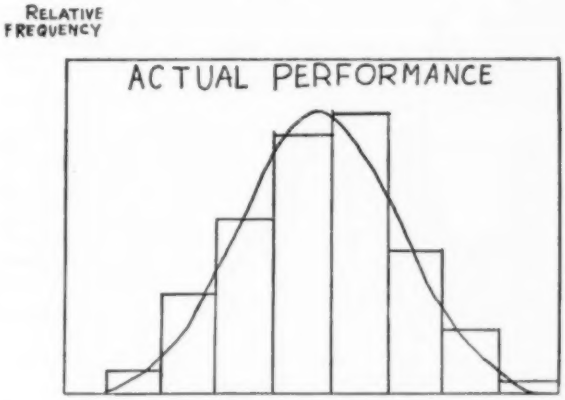


Figure 4

Figure 5

The control chart approacn not only helps Joe to answer the question, *Is a drop in the performance index significant?* It also helps to answer the more fundamental question, IS PRESENT PERFORMANCE SATISFACTORY? The answer is *No* if the performance is not in statistical control.

OTHER CONTROL TECHNIQUES

The control chart is ideally suited for use by busy management people in the line organization to control measurable work by employees under their supervision. The chart is simple. It tells the story.

Statistical techniques are also available for other aspects of managerial control (Fig. 5). Acceptance sampling plans, for example, are designed primarily for use in inspecting the quality of incoming materials with minimum expense. They are also suited to staff audits of the quality of work going out to customers or to other sections or departments. Such use should be preceded by statistical analysis as in designing control charts, so that the decisions as to the acceptability of the work will generally be the same as when the control chart technique is employed.

Continuous sampling plans are available for screening out enough defective work units to bring the average quality level up to some specified level. They are ideally suited to situations where a quality level is required that is higher than the standard index of quality as determined statistically. These situations, however, are likely to occur only where the specifications are fixed arbitrarily by people who are not acquainted with statistical quality control. The control chart principle, properly applied, nearly always results in maximum quality at minimum cost. It is being extensively used even where quality is a matter of life and death, as in manufacturing ordnance for the Air Force.

IN CONCLUSION

Organizing a successful program for managerial controls requires the meshing of several kinds of skills or qualifications, as follows:

1. *Statistical competence.* The control chart approach is not a simple, one-shot proposition. It requires careful study before the chart is installed, and subsequent research from time to time to keep abreast of current developments. It should be supplemented by other statistical techniques.

2. *Managerial know-how.* The statistician's tools do not correct situations where performance is not up to standard. They merely point them out. Experience in the field is necessary to taking the proper action to bring about improvement.

3. *Skill in human relations.* The statistical approach leads to the setting of reasonable levels of standard performance, and unbiased judgments as to whether these levels are being attained. But proper indoctrination is desirable to get acceptance of these facts by both the people who do the work and the people who supervise it.

Where a program has been properly and carefully planned, managerial controls invariably lead to better performance without increasing overall costs. In most cases, the combination of the skills enumerated above reduces costs substantially.

Statistical controls work because they help management people take prompt action in problem situations that are most in need of attention. They prevent wasting time when no problem is present.

Some Administrative Attributes of SQC*

DALE L. LOBSINGER

United Air Lines, Inc., Denver, Colorado

Where production and service processes are concerned statistical quality control probably has done more to clear haziness and indecision from the minds of management than any other technique developed in the past century. Note what Dr. Lloyd A. Knowler†, prominent teacher of the methods, has to say about their use:

> Probably the most important reason that quality control by statistical methods has been so successful in business and industry is that it is founded upon sound scientific principles. The hunches, the whims, the guess-work have been largely eliminated—the initiative is retained: in fact, additional time is left to management and employees for progressive and worthwhile reflection as to ways and means to improve their production at an economical level.

Our company agrees heartily with this statement, and for good reason. We have seen the following positive benefits accrue as the result of using SQC techniques:

- Improved service to our customers
- Reduced costs
- Reduced errors
- Aided supervision
- Improved training programs
- Provided continuous knowledge of performance quality
- Encouraged personnel pride in performance

These are all items of vital concern to the enterprise which hopes to engage successfully in today's highly competitive markets. They are not new, to be sure, in business's dictionary of responsibilities, but the increasing frequency with which they respond profitably to SQC treatment IS new.

The key to it all—that which provides SQC's most substantial contribution to modern management—is the cohesive nature of the SQC methods that makes possible a simultaneous and orderly treatment of factors such as listed above; and

*Presented on the program of the Industrial Clinic for Quality Control sponsored jointly by the Minnesota Section, ASQC, and the Industrial Engineering Division, Institute of Technology, University of Minnesota, in Minneapolis, October 16, 1953.

†Chairman, Mathematics and Astronomy Department, State University of Iowa.

this in turn makes easier a well-administered business organization.

SQC TELLS YOU MORE

The basic reason for much of SQC's success can be expressed quite simply. It tells you MORE! It provides more information about operating processes than previously was available through other means.

Just why is this important? It is important because increased knowledge about the nature of a process usually means improved control over the function. This in turn can lead to heightened efficiency and reduced cost. The reverse can be true, though, when there is an inadequacy of operating data. Consider, for example, the effect on pricing a product. When there is an absence of data to judge the extent of errors or scrap (just to take one area), the best competitive price on a product is difficult to achieve. The figure to the consumer must continue high enough to cover all waste, known and unknown; although it may be at a time when competition is able, through superior analysis and measurement techniques, to isolate and remove causes of defection — then drop prices in line with the savings.

For a broad range of businesses, statistical quality control is proving to be just the measurement tool management needs to gain the necessary data for more effective utilization of men, materials, and machines. It is providing a gage for production efficiency and a means for more accurately determining facility capacity under fixed conditions. In addition to this certain administrative by-products seem inevitably to emerge as management aids which fit well into overall organization responsibilities.

SQC IN AN AIRLINE

To better understand the foregoing, suppose we consider actual experiences which give the "before" and "after" picture related to the introduction of SQC. The story is one of an airline telephone sales office, an area substantially different from the thoroughly explored technical domains of the laboratory and factory, and yet one which shows a striking relationship for quality control approaches.

For some time following World War II a very trying condition faced our company in the telephone sales

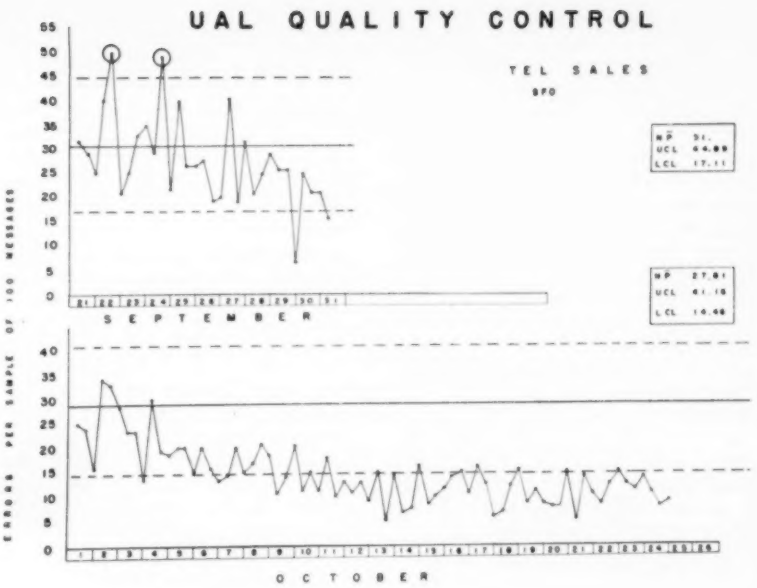


Figure 1

(reservations) activity. There had been a large increase in the number of people using air transportation, but our ability to accommodate their requests for airplane space had not kept pace. Performance breakdowns in this high-volume clerical activity subjected supervisors and agents to a heavy load of criticism. The standard means of analysis were applied in an effort to rectify the condition, but these were found ineffective. Known methods just seemed incapable of bringing pertinent data into focus for proper understanding and control. The situation gradually became an unhappy one, and the constant pressure of being 'under the gun' was becoming manifest through job transfer requests and lowered morale generally. Added to this was a sharp rise in frequency and intensity of customer complaints. Coincidentally, Mr. D. F. Magarrell, vice president of Transportation Services, encountered some material describing industrial use of quality control. He visualized an adaptation of the methods to our type of work and asked that appropriate studies be made to determine feasibility. Naturally, the telephone sales function was one of the first on which attention was centered.

Building an airline reservation into a final product which will meet the requirements of the flying public is a complex process. For each passenger a detailed chart record is kept showing flight number, date, destination, connections, ground services, telephone numbers, arrival information, return-trip information, etc. Much of this is recorded during the passenger's initial telephone contact, but a great amount also is accumulated in the form of wires, teletype messages, and interoffice communications related to various phases of the passenger's flight. In the larger offices thousands of such messages are processed each day—providing a "natural" for broad exposure to error. Significantly though, much of the success in selling our only marketable commodity, airplane space, is directly dependent on how well errors are minimized. Inaccuracies in any branch of the activity inevitably deteriorate our final service product to the customer.

At the time SQC analysis of reservations work was first considered, only hazy concepts prevailed regarding the true extent and nature of errors. This was not a situation, of course, about which we were especially proud; and our only consolation rests in the thought that we had always been trying our best, but just had not come upon the technique which could effectively handle the voluminous detail and complexity of our expanding business.

Following some preparatory research, the SQC project got underway with a sampling plan designed

to study groups of reservations messages throughout the working day. Notation was made of discrepancies between the contents of these and the information which appeared on the charts to which they referred. An np-type control chart was used for plotting quality levels and a data sheet was drawn up to depict errors by class, by employee responsible, and by time committed. Figure 1 shows a typical condition as initially revealed when SQC went to work.

Now the question of interest is, were we able to learn MORE about this reservation process and control it better than previously? Let us see.

Formerly the basis for judging work failures was that of random impressions growing out of isolated breakdowns. As a measurement of overall performance quality, this was at best limited and inconclusive. With our revised system, however, it was possible through an effective sampling pattern and an orderly arrangement of findings on a data sheet (Fig. 2) to know factually the nature and degree of defection.

THE SUPERVISOR AND EMPLOYEE ARE HELPED

The regular study of data sheets from day to day provided the supervisor with a cross-section view of the "who," "what," and "when" of troubles. Such unified information replaced what was once an inconsistent flow of data, and the random sampling of work made possible objective readings from which accurate and unbiased decisions could be made. This, SQC contributed.

Furthermore, there was an opportunity for more easily working out deficiencies of individual employees. Personnel came to understand that the SQC tool was a mutual aid that could pin-point weaknesses heretofore not evident. Training was then directed against their recurrence. At this stage it was exactly what was needed to boost sagging morale. The agents recognized immediately that here was a chance for improving job opportunity by "error-proofing" performance.

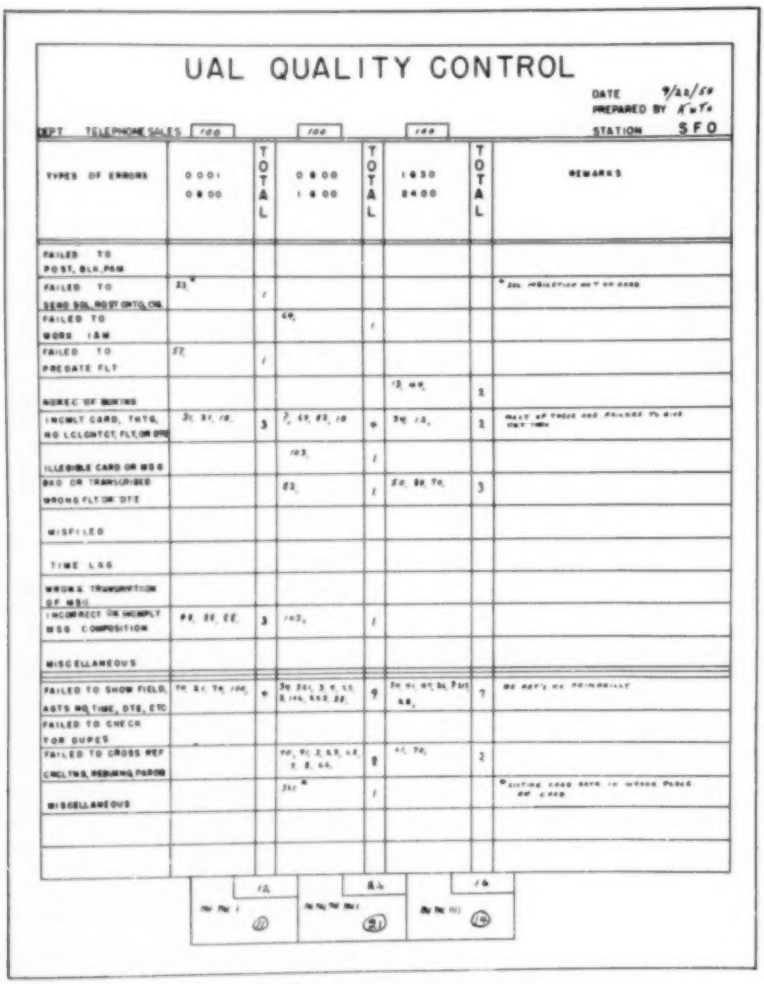
Moreover someone was showing an interest in the agent's work—and this was important! Perhaps while our business was expanding so rapidly, we like others had a tendency to overlook the efforts of the individual. We were to learn that this could be dangerous. It was somewhat as Dostoyeski, the famous Russian novelist, expressed it: "If the desire is to reduce man to nothing, it would be required only that we assign to his work the character of uselessness." Man needs to feel that he is a part—that he belongs. It is something that you want—something that I want. With the introduction of our SQC procedures, this once more became a possibility. Problems could now be brought into proper focus, and with the job know-how we already possessed, it was possible to work constructively toward removal of errors that had been damaging our service product. With it all our people became happier.

Did it work? Study Fig. 1 and notice the performance improvement over a 45 day period. Then look at Fig. 3 for exemplary progress at four stations where SQC methods were installed.

By and large employees and supervisors were pleased to learn that the chart and data sheet technique would help them to discover and overcome work failures. They were made to realize that the procedures constituted a cooperative venture to improve the lot of company and employee alike. Careful guidance by competent supervisors was important, of course, to the success of the program.

TRAINING NEEDS UNCOVERED

One surprising contribution, a by-product of the basic quality control effort, was evidenced in the training activity. By studying data sheets to determine the "what" and "who" of


UAL QUALITY CONTROL

DATE 9/22/59
PREPARED BY K.W.T.
DEPT TELEPHONE SALES 100 100 100 STATION SFO

TYPES OF ERRORS	0001 0800	TOTAL	0800 1600	TOTAL	1630 2400	TOTAL	REMARKS
FAILED TO POST, BLK, PNR							
FAILED TO SEND SEL. POST ONTS, ETC	33	1					* SEL. INDICATION NOT ON CARD
FAILED TO WORK I&W			49,	1			
FAILED TO PREDATE FLT	57	1					
INCORRECT BOOKING					12, 44,	2	
INCMPLT CARD, TWTG, NO LCL CONTCT, FLT OR DTE	31, 37, 10,	3	7, 49, 83, 10	4	39, 12,	2	MOST OF THESE WERE FOUNDED TO BE CORRECT WHEN
ILLEGIBLE CARD OR MSG			103,	1			
BAD OR TRANSCRIBED WRONG FLT OR DTE			83,	1	50, 88, 70,	3	
MISFILED							
TIME LAG							
WRONG TRANSMITTION OF MSG							
INCORRECT OR INCMPLT MSG COMPOSITION	88, 98, 88,	3	103,	1			
MISCELLANEOUS							
FAILED TO SHOW FIELD, ADTS NO, TIME, DTE, ETC	70, 87, 79, 100,	4	30, 34, 3, 9, 13, 2, 145, 882, 88,	9	34, 41, 47, 56, Post 68,	7	NO ADT'S NO. FOR MISSILE
FAILED TO CHECK FOR DUPES							
FAILED TO CROSS REF CKG TWG, REQUIRING PERSON			41, 91, 2, 8, 43, 43, 2, 8, 46,	8	43, 70,	2	
MISCELLANEOUS			31*	1			* DATING USED DATE IN WRONG PLACE OR CLOSED

15	24	14
17	21	14

Figure 2—Reservation Service Data Sheet

errors bothering us, it became apparent that the company had not been meeting fully the training requirements for this type of work. Frequently an agent confronted with a picture of his performance would indicate that he was not aware that he had been practicing wrong methods. The truth of the situation was that he had not been instructed adequately concerning the things which were expected of him. This quite clearly was a management responsibility.

Fortunately the SQC data sheets provided an excellent facility for correcting the deficiency. They furnished a distinct advantage over the customarily broad indoctrination programs by confining data in a manner that reflected personal idiosyncrasies and irregularities on the job. Isolating an individual's needs made it much simpler to organize training; for with up-to-the-minute performance data in his hands, the training agent could easily decide which persons needed help and those on whom it was unnecessary to spend time. This obviously could also work toward worthwhile time savings as is portrayed in Fig. 4.

Here we see illustrated performance in an office which had experienced rather excessive personnel turnover. The quality level during the first 12 days of the month had been running about seven or eight percent defective—about right for this class of work. On the eighth day of the month eight new people were employed. Instead of leading them through the usual five weeks of training, however, it was decided to give them eight days of instruction and then assign them to full-scale responsibilities. Progress was to be watched carefully through our SQC data.

As was expected, the error level increased immediately when these people started, and several times the process went out of control. Much to our delight, however, the erratic behavior lasted only a week. By following closely individual failures of the new people, it was possible to concentrate special training attention on them and within an elapsed period of about 17 days make them qualified to work right along with experienced agents. Our chart came back in control within nine days, and the basic training time was cut in half.

ESTABLISHING STANDARDS

The question of what constitutes good or bad performance is one that is ever present. We faced it in our reservations work, and it became especially provocative following the improvement wrought by SQC. What should we look for in terms of error levels? Is there a way that management can know when personnel and facility capacities are reached? The queries were not to be answered completely through SQC analysis, but there was a definite contribution.

In the first place we knew that we could not really satisfy ourselves concerning the quality and capabilities of the process until a measurement was devised to show its variability. Control chart techniques served excellently for this purpose. Once these had pictured process behavior to us, the first step of setting a standard was accomplished. From that point on job know-how, experience, common sense, etc., were

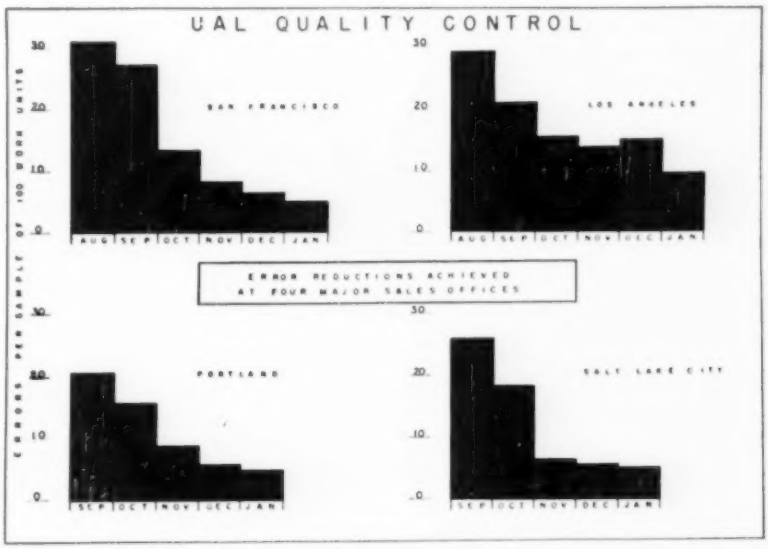


Figure 3—Exemplary Progress Through Application of SQC

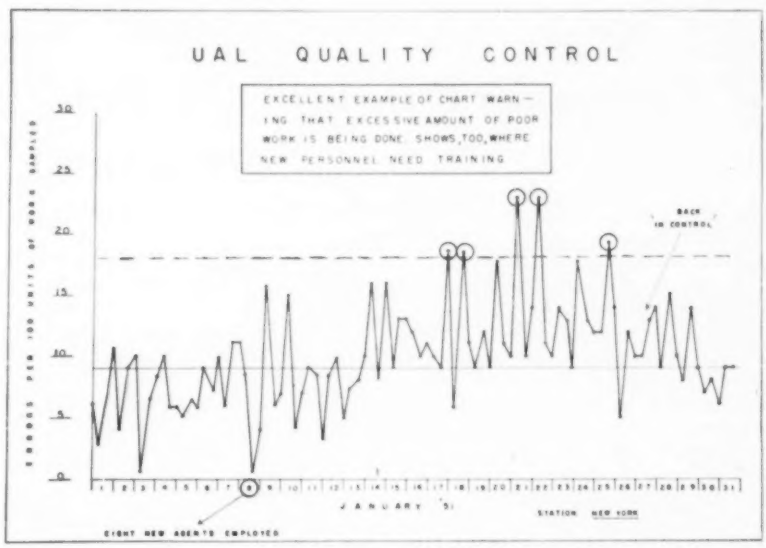

UAL QUALITY CONTROL
EXCELLENT EXAMPLE OF CHART WARNING THAT EXCESSIVE AMOUNT OF POOR WORK IS BEING DONE. SHOWS, TOO, WHERE NEW PERSONNEL NEED TRAINING
BACK IN CONTROL
EIGHT NEW AGENTS EMPLOYED
JANUARY '51
STATION NEW YORK

Figure 4—The Control Chart Is Sensitive to Personnel Turnover and Training Needs

invoked to remove assignable causes which created abnormal fluctuations. This was continued until variation was reduced to what was considered a most economical minimum. Then, and not until then, could we know what the standard was; only then could we know the quality of which the process was capable.

When you reach this stage, the basic philosophy of SQC becomes more meaningful. First of all, the phenomenon of inevitable variation is recognized as a natural characteristic of all processes. Secondly, this means that the work perfection so often talked about and so futilely sought is an impossibility. By coupling these two concepts it becomes apparent to management that a standard is pretty well fashioned by the process itself, after all assignable causes of defection are removed. It is not something to be imposed arbitrarily by personal will.

In our reservations work, for example, we had no means of knowing whether quality levels first encountered were good or bad. Much effort was required to ferret out causes for errors and make corrections through personnel training and facility adjustment before we arrived at a point where we considered we were doing about as well as could be expected.

A word here about this idea of perfection in work. It is not suggested that the precept be stricken from management procedures. Not at all! This is the only truly great inspiration to guide the world's progressive effort. But in industry it should be handled realistically—as a psychological aid rather than an edict. With it one must be careful to recognize human limitations, otherwise there is a tendency to push employees beyond natural capacities, and this generally foments organizational discord. The SQC tools, skillfully used, help us move closer to perfection—sometimes surprisingly close. It is always important to remember, though, that "to err (to vary) IS human."

THE FIELD IS BROAD

Telephone sales is just one place where we have profited through SQC. Opportunities for employing its philosophy and techniques seem endless. In United Air Lines, for example, our management has been aided by introducing the methods to accounting work, ticket sales, space control, food ordering, air freight billing, aircraft delays, aircraft maintenance, inventory controls, etc. These are fields relatively new to SQC, but from our viewpoint they constitute only a beginning. There are important things, for instance, that probably can be done in the area of personnel administration. Much seems feasible also where administrative reporting is concerned. The latter has been ably pointed out by Charles Bicking* who has done some fine pioneering in the realm. As indicated by Mr. Bicking, it is entirely possible that standard practice in the future could be to restrict periodic reporting of business affairs to a vastly simplified review of SQC charts. Just something to tell the facts—with a few pertinent recommendations added.

CONCLUSION

It would seem important for industry in general to recognize that besides the notable progress achieved with SQC in the technical spheres of the laboratory, factory, and machine shop, there yet remains the lucrative but lightly explored administrative areas which characterize most businesses of any size. Filing, invoicing, budgeting, letter writing, inventories, customer complaints, accounting, personnel data—these and many other phases of 'carrying on the business', are not too unlike the reservation detail described above. In many cases, moreover, they are crying for an improved method of analysis.

This writer strongly believes that once the movement is fully underway success with administrative applications of SQC will equal or exceed those in the technical branches of production. Additional gains will be limited only by the degree of imagination and effort.

*"The Application of Quality Control to Adminstrative Problems." *Industrial Quality Control*, May 1950.

Company Education in the Quality Problem

A. V. FEIGENBAUM

General Electric Co., Schenectady, N. Y.

MODERN quality control programs require for their effectiveness real understanding of modern plant quality conditions. They involve the identification of today's quality problems—rather than those of yesterday or the day before; the solution of these problems by the best, most up-to-date methods and techniques; the full understanding of current concepts of quality as they relate to company costs, sales, and production. The great, present-day interest of American management in the installation of modern quality control programs in American industry has inevitably, therefore, brought with it a major wave of company efforts to assure the further education of plant personnel in today's problems of building and maintaining quality products.

Within the last decade there have been literally hundreds of activities in this direction on the part of companies throughout the United States. A number of these educational efforts have been highly successful, judged by such standards as improved over-all company quality performance, and greatly increased quality effectiveness on the part of plant personnel generally. Many others of these programs have been as thoroughly unsuccessful, judged by the same standards.

What are the characteristics of successful company programs in quality education? Who should be educated in these programs and on what basis? Who should be the educators, and what should be their qualifications? Are such educational programs genuinely useful; do they really pay off? Or are they frills

during installation of a plant quality control program?

Questions such as these loom large nowadays in the minds of company managements and quality control engineers, faced with the necessity and responsibility for designing and having operated new quality educational programs, or with the comparable task of reevaluating and revamping existing programs.

The purpose of this article is to address itself to these questions, using as its backdrop the patterns for successful education in quality that have emerged from industrial experience of the past ten years.

THREE KEY CHARACTERISTICS REQUIRED BY PLANT PERSONNEL

The design, manufacture, and sale by a company of products of consistently good quality require a high degree of effectiveness in at least three key characteristics of plant personnel:

First: Their quality *attitudes.* Essential here is the genuine belief by company employees in the importance of good quality, excellent workmanship, well-conceived designs, service-centered selling.

Second: Their quality *knowledge.* Vital in this connection is employee understanding of the kinds of quality problems that bear both upon their individual jobs, and upon the plant in general; appreciation by the employees of the existence of up-to-date methods for solving their specific quality problems; positive acceptance by them of the principles, facts, and practices of modern means for building, maintaining, and controlling quality.

Third: Their quality *skills.* Important here are the abilities, both physical and mental, through which plant personnel actually perform the operations essential to quality as they are called for.

In effect, the company whose work force has sound quality attitudes, keen quality knowledge, and adequate quality skills is the company whose work force has the greatest likelihood of designing, manufacturing, and selling high-quality products.

OBJECTIVE FOR QUALITY EDUCATION

The basic management objective for company quality education may, therefore, be readily formulated as "the development for plant personnel—in all functions and at all levels—of those attitudes, that knowledge, and those skills in quality which may contribute to production of company products at minimum cost consistent with full customer satisfaction."

Such an objective is not a new one. Long before modern quality control programs had attracted widespread attention, plant managements were attempting to emphasize quality in the training of new operators, in the courses designed for foremen and supervisors, in the types of assignments used in the planned rotation of engineers and salesmen.

The objective is a broad one. Its achievement may involve, at a particular time in a specific company, the training of shopmen in the proper operation of Peterman-type lathes; the orientation of field maintenance men in the installation and service of a new product to be sold to consumers; the sending of inspection personnel to gage manufacturers' plants to gain intimate knowledge and skill in the use and application of precision gages of the air and electronic varieties.

The objective is one whose achievement can be based only in part upon the use of formalized classroom types of training. Much of the quality learning process—especially in attitudes but to an appreciable extent also in knowledge and skills—takes place very informally and almost imperceptibly during the course of a man's regular working day. Part of it is forced upon him during the finger-burning of on-the-job experience; a great deal of it comes about as a result of the daily contacts between the man and his boss; part of it results from the exposure of the man to his fellow workers.

The management quality education objective is one the means for whose achievement varies widely over periods of time. Quality problems have only one certainty: their content will be subject to continual change. Hence the solutions to quality problems will be a book to which chapters are constantly being added, but for which the final chapter is never written. Quality education never ends for the healthy, aggressive company whose products compete effectively in the fast-moving American economy.

QUALITY EDUCATION AS A PROCESS

So education in the quality problem is a process that, with varying degrees of effectiveness, has been taking place in industry for many years, in many forms, and in many ways. In their desire to modernize this process so as better to achieve the management objective for company quality education, realistic company managers and quality control engineers recognize that they begin with an existing fund of quality attitudes, knowledge, and skills—good or bad, current or hopelessly antiquated—on the part of company personnel. They recognize that they begin with a regularly functioning, informal learning process which is continually adding to this fund of education. They recognize that they begin with—to the extent that such activities have been in operation—a formal process of on-the-job, vestibule, orientation, and classroom training activities in job skills as related to quality.

It is interesting to observe that many of the modern quality educational efforts which have proved unsuccessful for American companies during the past ten years are those which have paid little or no attention to this principle: To determine where a man or a program or a quality educational activity is going, it is first necessary to learn where that man or program or educational activity has come from—and then act accordingly.

While much attention was lavished on their content and teaching methodology, the unsuccessful company quality educational activities never really fitted deeply into the company for which they were presumably designed. Some were offered prematurely; others were couched in quality terminology that completely threw overboard the traditional plant designations for rejects, losses, and quality faults; still others took no advantage at all of the quality educational process that had been going on in the plant for many years; collectively they never really came to grips with the company and its quality problems as they really existed at the time the educational programs were begun.

Experience seems strongly to indicate, therefore, that the first steps for a quality control engineer in appraising his plant's needs for modern quality education are (1) to analyze

carefully the existing company quality educational process, (2) to determine the characteristics of this process and its strengths and weaknesses, and (3) to build the educational planning with full relation to this information.

ANALYSIS OF THE EXISTING QUALITY EDUCATIONAL PROCESS

There are three basic questions that the quality control engineer will ask about the existing quality education process during this analysis.

QUESTION ONE: What are the scope, magnitude, and effectiveness of its formalized training for plant personnel in the specific job knowledge and skills that are required for the building and maintenance of good quality?

Even if a plant has an officially designated training staff which carries on all formal training activity and which may have ready well-organized answers for him on this question, the quality control engineer must go much deeper than the analysis that would be provided through this type of evaluation by men and women whose horizon is almost necessarily highly specialized. The quality control engineer should go to the grass roots of this training effort—to see and analyze himself, for example, the emphasis placed by the apprentice school on relative types of quality knowledge and skills; the amount of time that is actually spent in the vestibule room in providing to new operators job skills relating to quality; the reaction of foremen to the calibre of the knowledge and skills gained by employees in such training; the reality, as compared with the company's current quality problems, of the inspection training manual used in the plant.

If the company has no formal training staff, the quality control engineer may have to dig deeply even to establish just what formal training efforts in quality are being carried on by various sections and supervisors. It is vital that he establish such facts, for a major purpose of his analysis of the current quality education process is to gain a picture of the total hours—hence total dollars—being expended on formal training.

QUESTION TWO: What is the net effect on the quality thinking of plant personnel due to the informal, on-the-job, day-by-day influences of experience, contacts, and exposure that is so basic to the process of quality education in a company?

The single most useful criterion that the quality control engineer has with which to answer this question is the degree of quality mindedness that exists, section by section, throughout the plant. While no techniques for the quantitative measurement of quality mindedness seem yet to have been developed, quality mindedness can be sharply and readily appraised qualitatively by an experienced quality control man.

QUESTION THREE: What are the scope, magnitude, and effectiveness of its formalized efforts to train plant personnel in the modern concepts of quality, and in the programs and methods of modern quality control?

Typically in the early days of installation of a modern quality control program for a plant, the answer to this question is that almost nothing is being done. It remains, however, a very useful practical question to ask.

It is surprising how often material that relates directly to modern quality and its control techniques may turn up in some dark corner of the plant's educational process. Years ago someone may have inserted such material in a foreman's training course in which it has effectively, though obscurely, since been used. Possibly some supervisor or workman—to whom the terms $\bar{X}$, R, or p charts would be new language—has instinctively found how useful it seems to be to chart reject percentages or to tally readings on parts from certain machine tools—and this supervisor or workman has educated or is trying to educate those around him in the value of these methods.

Such home-grown material—as well as the people who have used and developed it—can be tremendous assets in any formalized quality control training courses being planned. To use such material, however, requires that the quality control engineer know that it exists.

USE OF ANSWERS TO THE QUESTIONS

Answers to these three questions provide the quality control engineer—who recognizes that the totality of the plant's quality educational process is one of the most important influences that must be utilized on behalf of the company's quality control program—with much of the basic material he needs for planning the types and kinds of modernization that must take place to bring this educational process up to date.

Specific action to be taken in the area of Question One—formalized training in specific job knowledge and skills as related to quality production—represents a major problem of industrial education in itself—the quality aspects of training apprentices, cadet or student engineers, new employees. As such, discussion of its details are beyond the scope of and space available for this particular article, but by no means beyond the scope of attention of an over-all, plant-wide modern quality control program.

Area Two—the informal process of quality education—involves for action solution to the various problems of developing and maintaining quality mindedness—again a major field for quality control attention in itself, although not possible of detailed discussion in these particular remarks. It might be noted that there has been a good deal of review on the quality-mindedness problem by quality control people in recent months; my own point of view toward this element of the quality educational process is represented in an article carried in the Convention issue of "Industrial Quality Control" for May, 1953.

Area Three—the formal training of personnel in modern quality problems and in control techniques—is the issue usually of prime interest to quality control engineers who are endeavoring to modernize their company's quality educational process. As such it is the area to which the bulk of the remaining remarks in this article are directed. Discussion is confined to the more general aspects of formalized quality control training.

FORMALIZED TRAINING IN QUALITY CONTROL

Members of the teaching profession, who have studied the learning processes of groups and individuals at all levels of the modern factory, have repeatedly told us of their unanimous conclusion: Adult men and women in industry—you and I among the many others—will learn and retain only those things which we think we need to know, which

we genuinely believe will help us in our work, which we think will most likely help us to solve the problems which daily plague us; those things which, in effect, we really want to learn.

It follows from this, and experience in quality education certainly confirms it, that the most effective quality control training courses are those which are quality problem-centered rather than quality theory-centered; those whose course content is built around specific assistance in helping men and women do their quality job better; those whose objective is the dissemination of principles and practices for solving basic, down-to-earth quality issues; rather than the dissemination of broad, general theories for quality discussion only.

The first and most universal principle in building a quality control training program, therefore, seems to be: Keep it down to earth and centered upon real plant quality problems. Concentrate upon practical, meaningful quality material.

Several other principles have simmered out of the past decade of industrial experience and may be readily cited:

Principle No. 2—In developing the quality control training programs, the quality control engineer and/or training staff should work and consult with the line organization to the fullest extent possible especially in regard to the scope and kinds of material to be used in the programs.

After all the line organization must do the bulk of quality problem solving for the plant and, from a marketing point of view, represents with its employees the customer for quality control training. Line people should, therefore, be encouraged to feel that course work is being carried on by quality control engineering as an assistance to the line rather than as a substitute for it.

Principle No. 3—The quality control training programs should be based upon recognition that the solutions to industrial problems, and therefore the solutions to quality problems, are always changing; consequently education in quality control methods and techniques can never be considered as completed.

It follows that participants in the quality control courses should be strongly encouraged to continue their education on a self-training basis after completion of the formal course, through whatever means are most appropriate for this purpose. It also follows that formal quality control training courses should have definite, organized provisions for periodic, brief refresher courses for plant personnel who have completed the basic training courses.

Principle No. 4—The training programs should, in the long run, include and/or involve as participants all levels of personnel from general management through to the skilled machinists.

Since interests and objectives differ widely among organization levels, individual courses in the quality control training program should be tailored to fit these several needs; no attempt should be made to force a single quality control training course to fit such widely different needs as those of the general manager, the quality control trainee, and the inspection foreman.

THE RANGE COVERED BY QUALITY CONTROL TRAINING PROGRAMS

In large plants a long-range program of quality control training may include any or all of such training activities as the following:

1. A brief and general course for first line supervision in modern methods of planning and controlling quality, concentrating essentially upon the physical elements affecting product quality. Such a course often will run three or four sessions, each of an hour or one and a half hour's duration.

2. A general orientation discussion for middle and upper management levels portraying modern quality control as a management planning and control technique, and concentrating upon the dollar and financial aspects of quality. Such a course often involves two or three sessions, each of an hour or one and a half-hour's duration.

3. Orientation training in quality for new plant employees. This work may be carried on as a part of regular new employee plant orientation activity.

4. A brief, simple, visual presentation to skilled workmen and assembly operators of some of the machine process and assembly aspects of quality control.

5. A course in methods and routines of practical quality control techniques for inspectors, laboratory men, selected foremen, and others whose daily work requires new and better quality training. Such a course may run from sixteen to twenty sessions and emphasize engineering, manufacturing, sales, and inspection phases of quality control. It will cover a general and brief review of the statistical methods that may be involved.

6. A detailed training course for individuals who may become full-time members of the quality control organization or whose work and background make such training desirable. Such a course may involve not only detailed discussion of practical quality techniques and methods, but it also provides a basic knowledge of the statistical methods that may be useful in a modern quality control program.

RESPONSIBILITY FOR QUALITY CONTROL TRAINING

Over-all authority for and cognizance of this broad quality control training program are the responsibilities of the plant quality control engineer, although the actual operating details of the training courses may be carried on for him by the plant training staff. Members of the plant organization are used to the widest extent possible as instructors and guest speakers in these courses, further to emphasize their quality problem-centered nature. Outside consultants may be profitably employed both in the early days of quality control training when the plant quality control engineer has not yet developed sufficient competency to direct the programs, and during the operating phases of the training programs so as to provide a broad point of view and an outside-the-plant perspective.

Of fundamental importance to the success of these quality control training courses is that they be consistent among themselves within the plant in the point of view they take toward modern quality control, and that this point of view also be consistent with the actual operating plant quality control policies and practices. There are, in general, two basic issues upon which most new quality control training programs have difficulty in regard to this matter of consistency.

They are:

1. What quality control is; in effect, what is the training course definition for quality control?

2. What is the scope of a modern quality control program to be considered in the training course?

Because of their essential nature in the building of internally consistent, up-to-date quality control training programs, this article touches on each of these two issues briefly.

First: Defining Quality Control for the Training Course

Suppose that quality control engineering is undertaking the development of a quality control training program. It will want first to outline the scope and responsibilities of the new activity. How is quality control to be defined for the course?

The quality control engineer may immediately encounter a difficult problem. During the past several years, the term "quality control" has been applied to most of the proposals that have been advanced for improving product quality and for reducing the cost of its maintenance. The activity has come to have almost as many definitions as there have been systems proposed for its use.

Is quality control for training purposes to refer to a series of sampling inspection methods? Is it to designate the troubleshooting of factory reject problems? Is the activity to be made synonymous with industrial statistics?

These definitions refer to individual methods for controlling quality. A quality control engineer whose objective is establishment of truly problem-centered quality control training programs would reject them as being too restrictive.

He would conceive of quality control as the over-all, factory-wide program for attaining management's quality goal. Such a broad program includes many of these individual methods, to be sure — preventive maintenance, inspection planning — but its primary function is the organization and administration of these several methods.

The quality control engineer would want the definition for quality control for use in the training course to mirror this administrative point of view. He would accept one such as the following: "Quality control is the company system for programming and coordinating the quality maintenance and quality improvement efforts of the various groups in the organization so as to enable production at the most economical levels which yield full customer satisfaction."

The maintenance of tools so that they will produce satisfactory parts is recognized as a quality control activity under this definition. So is the periodic check of thread gages, the analysis by draftsmen of tolerance build-ups, the use of machine floor inspectors, the determination of the accuracy of the machine tools, the use of sampling inspection plans.

A more popular, slogan-like version of the definition might readily be used. It states that quality control means programming the job of making the product right the first time at the best cost which will result in satisfied customers.

Whether the definition used for internal training course consistency is a slogan-like one of this sort or one which is more formal is largely a matter of taste; what is important is that it is definitions of this type that would be used as the foundation for the development of modern quality control training programs for a present-day plant.

Second: Scope of a Modern Quality Control Program

What scope for modern quality control should be accepted by the training course? What methods should it consider as being used in quality control? Are its discussions confined to inspection work? Are production and engineering considerations involved?

Answers here depend upon the determination of still more basic questions: What affects the quality of a product? Where is it affected? During design? During machining? In final assembly? How is the quality affected? Who affects it?

Those factors which may have important effects on product quality must be controlled if management is to attain its quality goal for the product. It is the consolidation into an over-all program of various techniques for this control which constitutes a complete quality control program.

A company product passes through many hands and processes before it is finally received by the customer. It is merchandised by a marketing group which broadly establishes the product specifications. It is designed by an engineering group which turns these requirements into actual factory standards. Its materials are procured by a purchasing group which has an important effect in determining the quality of these materials. The jigs, tools, and fixtures for its production may be developed by a methods group. Parts are manufactured and assembled by a production group. Materials and life-test performance may be approved by a laboratory group. Conformance to standards is checked by mechanical inspection and electric test groups. The container in which the product will be transported may be developed by a packaging group. The product is placed in its container by a shipping group.

Quality of the product may be adversely affected at several of these stages in the production process. It may be affected by human beings — operator carelessness, inadequate supervision, poor design, unsound specifications by the sales manager. It may be affected by mechanical factors — inaccurate machine tools, decrepit jigs and fixtures. It may be affected by natural causes—dust in the air which coats over the product contacts, excessive humidity which causes chemical action on the parts.

So the modern quality control training course would recognize that a complete quality control program starts with the design of the product and does not end until the product is placed in the hands of a customer who is satisfied with it. The activities to support this program fall into four natural classifications, sometimes called Jobs, which are:

1. The control of new designs and new products, or "New Design Control."
2. The control of incoming purchased parts and materials, or "Incoming Material Control."
3. The control of parts and batches from machines, processes, and assembly lines, or "Product Control."
4. The conducting of special tests of factory and processing problems, or "Special Process Studies."

The training course would emphasize that these four quality control activities gear directly in with the over-all production cycle of a plant, and are supported by definite routines. These routines are approved by plant management in accordance with a definite plan. They are part of factory practice just as are production control or cost control routines. The course would emphasize that the existence of these routines and their integration into an overall system are the very heart of a genuinely effective quality control program.

CONCLUSION

In summary, therefore, the top management objective for company education in the quality problem may be clearly stated: It is to develop for plant personnel—in all functions and at all levels—those attitudes, that knowledge, and those skills in quality which may contribute to production of company products at minimum cost consistent will full customer satisfaction.

This objective—which is by no means new—has historically been achieved by a broad process of quality education which involved not only formal quality training courses but to a large extent many informal quality influences. The modern quality control engineer recognizes that part of his task must involve assuring the modernization of this process in three major areas:

1. Formal training courses for the development of quality control types of knowledge and skills.
2. Formal training courses for the development of specific job-centered quality knowledge and skill in such areas as machining, processing, inspection.
3. Those informal influences upon plant personnel which have major effects upon the degree of their quality mindedness.

Throughout, the quality control engineer recognizes that the totality of the plant's quality educational process is one of the most important influences that must be brought to bear in behalf of the company quality control program. He also recognizes that sound company education in the quality problem is one of the most vital elements in achieving the basic quality control objective: to manufacture products into which quality is built and maintained at the most economical costs yielding full customer satisfaction.

Industrial Training of Quality Engineers And Supervisors*

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A supervisor or engineer in industry normally improves in ability and value through one or more of four possible types of training. These are:

Experience Training—primarily self-acquired on the job by contact with the day-to-day problems.
Guidance Training—from personal contact with his superiors (sometimes with subordinates or equals) as they advise him on methods and actions.
Independent Study—classes, technical meetings, study of books, etc., undertaken on his own initiative, without direct company sponsorship, and primarily in the direction of his personal interests and ambitions.
Company Classes—training through classes or conferences conducted, or sponsored, by the company and in the direction of the company's interests.

More and more, companies are putting an increased emphasis on the last type of training—not because such classes are a satisfactory substitute for experience, guidance, or initiative; but because they are a necessary supplement when there is insufficient time or insufficient employee ability to depend solely upon the other three.

This is particularly true in many quality control groups, where new techniques and the handling of new functions must be learned by incompletely trained employees, or by employees trained through experience in older ideas and methods.

The writer recently secured information from inspection and quality heads in 56 companies regarding their training of inspection and quality supervisors and engineers. Of these, 48 either conducted company classes or paid for outside extension courses for at least some of their quality personnel, and 26 did both. However, over one-third of these men expressed dissatisfaction with their training programs and believed additional or improved training desirable.

It is the purpose of this paper to discuss some of the general planning and methods for class-type training of inspection and quality control supervisors and technicians in the hopes that this may be of help to the many companies requiring better training for this group.

NEED FOR TRAINING

The need for training is basically a function of the quality group's ability to handle its quality responsibilities. It can be measured by the complexity of the quality problems, the education, experience, and initiative of the quality personnel; and by the current rate of improvement in both the quality personnel and, solution of quality problems.

To those companies who are in doubt as to whether or not they require improved training, the writer suggests the following simple test:

1. Have you been able to satisfactorily fill most of your top and middle-level inspection and quality openings by upgrading from within during the past few years?
2. Are your inspection and quality supervisors and engineers becoming of increasing value to the company and advancing steadily in both responsibility and rate of pay?
3. Are many of this group doing independent outside study of newer quality control methods through extension courses, attendance at ASQC meetings, reading of technical books, etc.?
4. Have continuing and important improvements been made in your methods of machine control, gaging and testing; in your analysis and use of inspection and test data; your selection and supervision of inspectors; and in your

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general level of employee "quality consciousness" during recent years?

5. Have your quality problems reduced in seriousness and has your ratio of quality costs (including inspection labor, scrap, rework, etc.) lowered over the past year?

If your answers to several of the above are "No," you would do well to carefully consider the reasons; it is the writer's belief that you will find insufficient training of your key quality personnel to be an important factor.

PRELIMINARY APPROACH TO TRAINING

Before embarking on the details of what, when, where, and by whom training should be conducted, it is suggested that companies planning extension of their quality control training give consideration to the following:

1. *Make sure the personnel to be trained are suitable.* The training objective, the training method, and the caliber of the personnel available for training are all tied together. One cannot be considered logically without consideration of the other two. Training of any type is like manufacturing itself, in that it requires first a design of what we wish to turn out; secondly, raw material from which the product is to be made; and then thirdly, a process for transforming the raw material into the finished product. No worthwhile training program can be established without full consideration of what is actually desired and what is available to make it from. The greater the spread between these two points, the more extensive is the training required.

If the available personnel are not capable of being transformed into what you desire, then you must either lower your sights for the end results, or secure better quality material at the start. This does not mean that you must have top grade engineers before you can have a successful training program, but if you really require quality control engineers trained in statistics, in test and inspection methods, in gage selection or design, in technical investigations, in report writing, and in the selection and supervision of inspectors; then you require a level of mental ability and training comparable to those for design engineers, C.P.A.'s, or research chemists. Do not attempt to make full-fledged quality engineers from personnel you would unhesitatingly reject for other equally complex positions.

2. *Consider possible changes in personnel.* In planning your training program, take into consideration possible changes in your products and organization, and especially consider possible turnover in your personnel. Some companies have embarked on long term programs for one or two picked employees only to have these men leave the company or be promoted to other jobs before putting their training into use. Such changes can never be completely foreseen, but their seriousness can be reduced by advance consideration, inclusion of understudies in at least a portion of the program, and coordination of definite upgrading with your training program.

3. *Encourage cooperation from the men to be trained.* Discuss your training needs and preliminary plans with those men who are to be trained, in advance of establishing a definite program. To do so will not only give you the benefit of their ideas, but will also encourage their cooperation from the start. It is entirely possible to initiate a training program by either direct or indirect compulsion upon the trainees. However, if after a few sessions the men being trained are not sufficiently interested to actively desire continuation of the training program, then they may as well be dropped from further training. Without their wholehearted interest and cooperation, it will not succeed. It is extremely helpful if this cooperation can be secured at the beginning of the program.

Plan the details of your training program to encourage the continued cooperation and support of those being trained. This includes making sure that the classes are as interesting as possible through careful selection of the instructor, use of visual aids, models, etc. It also includes consideration of such details as time of classes, comfortable facilities for classes, payment for meals if classes are outside of regular working hours, supplying of interesting texts, and class visits by top executives.

Plan, also, so that if some of your trainees drop from the program, either by their own choice or because it has become apparent that they are unable to absorb further training, that this can be done without their embarrassment or discouragement.

4. *Plan the training program completely but allow for possibility of changes.* In planning your training program, plan it completely on a long range basis but provide for frequent reviews and changes in the tempo or subject matter whenever this appears desirable.

5. *Plan cooperatively with your Training or Personnel Department.* In those companies with active Training Departments, any training program will, of course, be coordinated with their work and much, if not all of the planning will become their responsibiity. Even if your company has no such department, or if they are unable to handle the quality training program, every effort should be made to have the Personnel or Industrial Relations section an active partner in the program. In addition, if your company has generally unfilled training needs, the introduction of a quality training program may well be the occasion to consider an overall training responsibility to coordinate administrative and planning details. However, in any event, the Quality Manager or his superior must also assume his share of the responsibility for the technical planning.

6. *Consider possible inclusion of other departments in the training.* Frequently, industrial engineering, design, research, and production personnel can profit from some of the same training planned for inspection and quality control. Inclusion of these groups may not only benefit the other departments but will also improve inter-department cooperation and understanding.

SUBJECTS TO BE TAUGHT

The actual subjects in which training is required will, of course, vary with each company and may include such diversified items as statistics, precision measurements, bacteriology, metallurgy, personnel supervision, inspection work simplification, job evaluation, etc. Likewise, the degree of training required in each subject will vary with each company, and precision measurements to one may require training

in use of a micrometer and to another require instruction in surface plate gear checking.

The training program must be established by someone who knows both the company methods and problems and also knows the latest techniques in those fields. Where this latter knowledge is not available in the company, it will be necessary for the executive responsible for the quality group to secure outside advice. In such instances, the local ASQC Section should be able to provide assistance.

In most cases, it will prove helpful to list the requirements for each quality job and record the present degree of competence of the employees.

Comparison of job descriptions, as presently performed, and as desired, will also highlight training needs.

TYPES OF TRAINING CLASSES

Once you have decided that a training program in specific subjects is desirable, the final considerations will be where, when, how, and by whom such training shall be conducted. The decision as to whether classes shall be on company time or employees' own time is one in which company policy and, in some cases, labor laws or contracts must be considered, as well as the availability of the men during working hours. The various types of classes are discussed below.

1. In-Company Classes. In-company classes have several important advantages over most extension courses conducted outside. They permit the group to work with actual company data on company problems and permit guidance of the training in the specific directions most valuable to the company. They also permit better evaluation both of the men being trained and of the effectiveness of the classes. Where necessary, changes in the speed or direction of training can be made much more easily than in a program of outside courses.

The major drawback to in-company classes is the securing of a qualified instructor. If one is not available within the company, it is sometimes possible to secure outside experts from local colleges, other industries, or consulting firms, but here much of the advantage of specific company knowledge and direction is lost. One other method, which the writer has used with some success, is the practice of having various members of the training class themselves teach specific portions. This requires that they study this phase in advance and therefore frequently learn it themselves better than they otherwise would. It also gives them valuable experience in teaching and in preparing technical notes and reports. However, it should be kept in mind that this method can only be used if there is some overall guidance and if the selected men have initiative plus a preliminary basic knowledge of the subject.

In-company classes have an additional disadvantage in that the training is sometimes so specific on company problems that the trainees fail to grasp a broad or fundamental understanding of the ideas or methods being taught.

It is the writer's recommendation that in-company classes be used only under the following conditions:

a. The subject to be taught is not a general one or else specific advanced training is required. (Good general courses in measurement, inspection, statistics, etc., may be too readily available in most areas to warrant special in-plant classes unless the group is very large and qualified teachers are easily available within the company.)
b. There are more than three or four persons to be trained in the same subject.
c. An instructor is available either within the company or from the outside, who both knows the subject expertly and has the ability to convey his knowledge in an interesting manner.
d. Someone in the company (or the outside instructor) can take time to carefully plan the classes, prepare interesting examples, models, etc.

2. Outside Extension Courses. The outside extension courses conducted by a technical school or a technical association normally have better teaching equipment than available to the company classes. The quality of the teaching staff may, however, be inferior with respect to practical experience and too many extension courses tend too highly toward the theoretical. There are, however, many notable exceptions of excellent extension courses taught by experts in the industrial applications as well as in teaching methods. (This is particularly true of many of the part-time and the full-time short training courses available in the statistical aspects of quality control.)

Generally, the writer suggests that outside extension classes be used (where available) in preference to company classes, provided the course content and the teacher's ability have been carefully checked and found to be suited for the training required. Under these conditions, the quality of training will usually be better and appreciable time saved for the company staff.

Unfortunately, extension courses are presently not generally available in many phases of inspection and quality control for which industrial training is desired. The comments in a recent sampling of inspection and quality managers indicates that most believe such subjects as production trouble shooting, personnel management, inspection work simplification, gage design, and automatic controls have been too largely neglected by colleges and technical associations in their extension training. On the other hand the statistical techniques of quality control have perhaps been overemphasized. (In fairness to the universities and ASQC it should however be kept in mind that the techniques of such subjects as gage design and production trouble shooting are quite specialized by type of industry; whereas, the same general statistical techniques can be taught with less regard for product and process differences.)

It is hoped that the difficulties of extension training in additional quality control subjects can be overcome and it is suggested that the ASQC and its interested members give the problem their attention. In areas where there are several generally similar industries, grouping of their requirements could make possible such courses conducted either by technical colleges or by the ASQC Section itself.

3. Study of Technical Books. There are presently available excellent training texts in several phases of inspection and quality control and, if other means of training are unavailable, it should be entirely practical to train primarily by a program of home study, under the following conditions:

a. The trainees must have a real interest in learning and initiative to work alone at home.

b. The text must be suited to the prior education of the trainees.

c. Definite sections to read and problems to be solved should be assigned weekly and problem sheets reviewed by the "instructor" (who, of course, must have at least studied and understood the text).

d. Short group conferences of the instructor and trainees should be scheduled weekly, at a regular time, to discuss current studies. (Occasional outside speakers or the showing of training films on statistics, gaging practices, etc., can also be used to advantage at these conferences.)

SUMMARY

In summary, the writer suggests the following approach to training:

1. Determine your training needs, including the subjects and extent of training required in each.
2. Make sure your personnel is suitable to profit from the training.
3. Plan carefully in advance to secure the cooperation of the trainees, as well as of other groups in the company.
4. Use outside extension courses, where available, but only after making sure they are suitable.
5. Use company classes where necessary and make every effort to secure competent instruction.
6. Where limitations of qualified instructors, organization or company policy prevent the training believed desirable, utilize whatever methods are available, as long as they permit some progress in the desired direction. Training can be done by encouragement of home study or by group discussions, where these are the only immediate approaches.
7. Call upon ASQC for assistance and attempt to secure its activity in all phases of quality control—not just in the statistical techniques.
8. Realize that training classes are only a supplement to proper selection, guidance and upgrading of employees. Use them as an aid, not a replacement, for good personnel policies.

The Sampling Operation in Acceptance Sampling of Glass Containers

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The growing use of acceptance sampling in the glass container-using industry has opened up the question of how the sample should be taken, whether in shipping case units, or by an individual bottle or bottles from the shipping case. The same methods apply in any other industry where the combined product from several machines or multiple spindles is packaged in groups.

Every acceptance sampling operation costs money. If the strict rules of random sampling can be set aside to some extent, sampling costs can be reduced. Many receiving departments attempt to do this, but sometimes with disastrous results. The problem is—where to reduce with safety in judgment of the quality of a shipment. Several practices can be summarized:

1. Taking only enough shipping cases to give the total units required, and from one portion of the shipment.
   (Extremely unwise—because of possible stratification.)
2. Taking shipping cases at random, but only enough to give the required quantity of bottles.
   (Normally unwise—to be used with extreme caution.)
3. Taking one bottle from any one shipping case, with the cases from one portion of the shipment.
   (Often satisfactory, but still unwise if shipment stratified.)
4. Taking one bottle from each different shipping case, with cases selected at random.
   (The only completely sure method but high in labor cost.)
5. Taking a statistically determined number of bottles at random from a statistically determined number of random selected shipping cases.
   (A compromise which we recommend.)*

In order to visualize the problem of shipping case vs. individual bottle, some idea of the relationship to manufacturing process should be understood.

Production of glass containers is made on machines which may have as few as four bottle-making cavities or molds, or as many as 45 cavities. The molds discharge to a single line in a fixed cycle or order of production, since all the bottle-making cavities are mechanically linked at the same speed, either in a single rotating machine or in a straight line operating on one shaft.

The single line conveys the bottles to an annealing oven, or lehr, through which bottles progress in parallel rows. Several methods of loading the oven may affect the sampling method, of which the following are the most common:

1. Individual or dual "stackers" which place the bottles in a pattern on the moving lehr belt, first on one side, then on the other.
2. "Pusher bars," in which a complete row of bottles, not necessarily the same as the number of bottle-making cavities, is pushed from the single line to the lehr belt in an intermittent operation, timed to the speed of the lehr belt and the forming machine.
3. Dual pusher bars, similar to the preceding but with two single lines from the machine and crossing the front of the lehr from opposite sides, meeting in the middle.

*Note: This procedure is now specified in ASTM Tentative Method of Sampling Glass Containers, C224-53T.

There is no fixed relation between the number of bottles in each cross-row in the lehr, and the number of cavities making bottles on the machine. The number of bottles in the row is fixed by the width of the belt, the diameter of the bottle, and the necessary distance between bottles. In many instances the number of bottles will be the same as the number of cavities, but in many other instances it will not be the same number. This will make a difference at the packing end of the operation.

When the annealed bottles emerge from the lehr, any one of several packing methods may be used.

1. Complete manual handling — where from two to six or more operators remove bottles from the belt by hand, in groups of two, three or four bottles at a time, packing these bottles in cases for shipment after examining each bottle. According to size of bottle, from 4 to 144 bottles may be placed in the same shipping case, the most common number being 12 or 24 bottles in a case.

1a. Here the effect of lehr-pattern is most important. If the number of bottles in a row across the lehr is the same as the number of cavities on the machine, or a whole number multiple of that number, the lehr-belt will be "stratified," in that all the bottles in any one column of bottles coming through the lehr will be from the same cavity. (See Figure 1.) If, for example, there are eight bottles in each row across the lehr, eight mold-making cavities, and two packing operators on each side of the lehr, then each operator will take bottles from two columns of bottles coming down the lehr belt. Thus, the cases filled by that operator will contain bottles from only two bottle-making cavities.

1b. To further complicate matters, in some instances each packer places the shipping cases from his operation on a separate warehouse truck than the other packers. As many as 100 of these cases might be thus segregated, containing representatives from only a portion of the bottle-making cavities, and thus go to the truck or railway car as a unit, and then loaded as a unit. This is what makes sampling from one portion of a shipment extremely unwise in acceptance sampling.

1c. When the number of cavities making bottles is not the same as the number of bottles across the lehr, or not a whole-number multiple or sub-multiple of this number, there will be no stratification of cavities in columns through the lehr, but instead a mechanical pattern, reproduced in cycles. This will give a greater representation of cavities in each shipping case, and a little more safety in treating a whole shipping case as part of the sample. In some instances, however, a few cavities will predominate in any one shipping case. (See Figure 2.)

2. Other methods of packing divert streams of bottles from the lehr. In some instances the bottles will be mechanically mixed, but in other instances, stratification existing in the lehr will be continued to the final packing operation. No certainty of pattern can be expected, since the same bottle may be made by different methods, by different makers, or by different methods by the same maker.

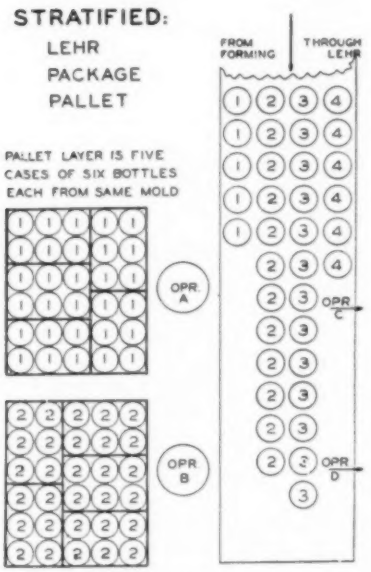

Figure 1—Stratified Packaging

The glass-forming machine using four molds is making a bottle of such width that four rows of bottles come through the annealing lehr. Thus, each row is composed of bottles from one mold only. Operator A removes the first row for examination, and because these are all from mold No. 1, the shipping containers and the warehouse pallets are stratified in that only one mold is represented. Operators B, C and D perform similar functions.

In order to test the effect of different methods of operating, three studies have been made of the number of bottles from each mold cavity, in lots of approximately 200 shipping cases each. All were packages of 24 bottles each, and the study involved determining the frequency of each mold cavity represented.

Study No. 1

The first example is one of a condition where no stratification existed in the lehr. A forming machine having only four bottle-making cavities was used, and there were six bottles across the lehr. Thus, bottles from the same cavity were not in one column through the lehr but in the 1st, 3rd, and 5th, or in the 2nd, 4th, and 6th columns in equal numbers. (If either one of the cavities or the columns were an odd number, the distribution would be uniform in all columns, but since each packer took two rows at a time it made no difference in this instance.) Since there were 24 bottles to the shipping case, and only four operating cavities, the range of frequency in each shipping case was somewhat larger than in the later studies.

In Tables I and II are the results for the individual cavities and for

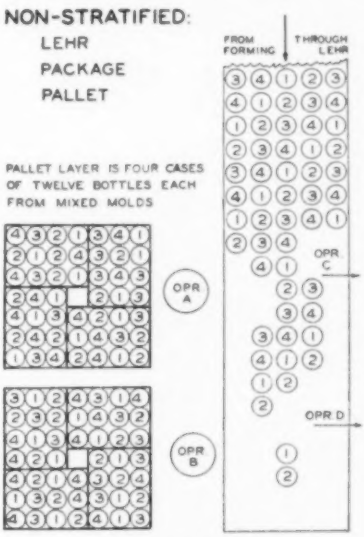

Figure 2—Non-Stratified Packaging

The same bottle-making machine carrying four molds is now making a similar bottle which results in five rows through the annealing lehr. The individual rows are not stratified. They represent mechanical mixing. Even though Operator A removes only the first row, plus a few occasionally from the second row in order to balance the work load, neither the shipping containers nor the warehouse pallets are stratified.

TABLE I—Study No. 1—Distribution of Cavities per Shipping Case, 200 Cases

Number of Each Cavity in Case	Individual Cavities 1 Frequency	2 Frequency	3 Frequency	4 Frequency	Combined Cavities Frequency
0			5		5
1	2	1	8	3	14
2	4	1	6	1	12
3	18	7	14	12	51
4	32	20	29	13	94
5	25	30	42	42	139
6	48	31	38	44	161
7	32	46	27	33	138
8	23	40	19	26	108
9	14	15	8	14	51
10	1	6	2	8	17
11	1	3	1	2	7
12			1	2	3
Total Bottles	1150	1310	1072	1258	
Ave. per case	5.75	6.55	5.36	6.29	24.00
Ave./cavity/case					6.00

TABLE II—Study No. 1—Frequency Analysis of Cavities per Shipping Case, 200 Cases

Number of Each Cavity in Case	Combined Cavities Percent Frequency Actual	Theoretical
0	.6	.2
1	1.8	1.5
2	1.5	4.5
3	6.4	8.9
4	10.8	13.4
5	17.4	16.1
6	20.1	16.0
7	17.4	13.8
8	13.5	10.3
9	6.2	6.9
10	2.1	4.1
11	.9	2.3
12	.2	1.1
13		.5
14		.3
15		.1

the combined cavities. The four columns for individual cavities add up to 200 observations (shipping cases) while the column for the combined cavities adds up to 800 observations. Thus, the 14 instances where one of a cavity was found in a shipping case, are made up from two times for cavity number 1, once for cavity number 2, eight times for cavity number 3, and three times for cavity number 4. Since only the combined cavities are detailed in studies No. 2 and 3, it is well to note how the combinations were made.

In this study it is shown that the four cavities are present in substantially equal numbers, except for losses on inspection. This indicates absence of stratification, for which reason the entire shipping case *could* be taken as part of a large sample. Note that the actual frequencies are less than the theoretical frequencies at both ends of the curve and more at the middle. This is due to the fact that the bottles taken by the selector-packer at any one time were from a small portion of a cyclic pattern immediately in front of her and not from a large "universe."

Study No. 2

In this production the lehr was stratified, in that, 16 mold cavities produced bottles, and the lehr pattern was in rows of 16 bottles across the lehr. Two streams of bottles were removed from the lehr, but there was some mixing of bottles before the streams separated. One hundred ninety-four shipping cases were examined, recording the frequency of each cavity representation in each case of 24 bottles. All shipping cases came from one of the streams.

It was found that eight cavities were found more frequently, and eight cavities less frequently, being the result of the preliminary stratification and the partial mixing described in the preceding paragraph. It was also found that the frequency in the shipping case varied from none to seven bottles. Table III shows the results obtained.

Since the average of the eight most frequent cavities was 2.406 per case, it is possible to estimate the theoretical frequencies from the Poisson distribution, and also for the average of 0.594 per case in the less frequent eight cavities. These results appear in Table IV.

As already pointed out, there is a definite reason why the actual percent frequencies are less at either end of the curve and higher in the middle. The packer is not packing a "sample" from the entire universe, but from a small mechanical and cyclic portion passing immediately in front of her at the moment. The universe from which each sample comes is a small mechanical mixture from a stratified stream. This phenomenon appears in all three studies.

There is also a variation from theory, in that bottles are being discarded from the stream for cause by the inspector. This tends to lower the frequency, except that the theory is calculated on the average pack.

Study No. 3

This was a repeat of the second experiment, but from 90 shipping cases from each of two streams. There is a definite confirmation of the fact of stratification since the eight cavities that appeared most frequently on one side of the lehr were the same eight cavities that appeared less frequently on the other side.

Tables V and VI show the same general analysis as in the previous tables, leading to the conclusion that the variability is within reason when the stratification is recognized. They also lead to the conclusion that it is unwise to take full shipping cases of bottles as part of a sample, since knowledge of possible stratification

TABLE III—Study No. 2—Distribution of Cavities per Case, 194 Cases

Number of Each Cavity in Case	Combined Frequency 8 Most Frequent Cavities	8 Less Frequent Cavities
0	99	847
1	291	534
2	462	137
3	393	25
4	213	6
5	77	3
6	16	
7	1	
Total Bottles	3734	922
Bottles/cavity/case	2.406	.594

TABLE IV—Study No. 2—Frequency Analysis of Cavities per Case, 194 Cases

Number of Each Cavity in Case	Percent of Combined Frequency 8 Most Frequent Cavities Actual	Theoretical	8 Less Frequent Cavities Actual	Theoretical
0	6.38	9.1	54.57	54.9
1	18.75	21.7	34.41	32.9
2	29.77	26.2	8.83	9.9
3	25.32	20.9	1.61	2.0
4	13.72	12.5	.39	.3
5	4.96	6.0	.19	
6	1.03	2.4		
7	.06	.9		
8		.2		
9		.1		

TABLE V—Study No. 3—Distribution of Cavities per Shipping Case, 90 Cases Each from North and South Sides of Lehr

Number of Cavities in Case	Combined Frequency			
	North Side of Lehr		South Side of Lehr	
	8 Most Frequent Cavities	8 Less Frequent Cavities	8 Most Frequent Cavities	8 Less Frequent Cavities
0	65	375	52	488
1	130	251	115	192
2	204	73	192	38
3	176	17	178	1
4	103	3	106	
5	36	1	45	
6	5		26	
7	1		6	
8				
9			1	
Total Bottles	1695	465	1889	271
Bottles/cavity/case	2.35	.65	2.62	.38

TABLE VI—Study No. 3—Frequency Analysis of Cavities per Shipping Case, 9 Cases Each from North and South Sides of Lehr

Number of Cavities in Case	North Side				South Side			
	8 Most Frequent		8 Less Frequent		8 Most Frequent		8 Less Frequent	
	Actual % f.	Theory % f.	Actual % f.	Theory % f.	Actual % f.	Theory % f.	Actual % f.	Theory % f.
0	9.02	9.6	52.08	52.2	7.22	7.3	67.78	68.4
1	18.06	22.0	34.86	33.9	15.97	19.0	26.67	25.7
2	28.33	26.7	10.14	11.1	26.67	25.0	5.28	5.2
3	24.44	20.6	2.36	2.4	24.72	21.9	.14	.6
4	14.31	12.1	.42	.3	14.72	13.9		.1
5	5.00	5.7	.14	.1	6.25	7.6		
6	.69	2.2			3.61	3.2		
7	.14	.8			.83	1.3		
8		.2				.5		
9		.1				.1		

is not usually available at the place where the acceptance sampling takes place.

In order to employ the true principles of random sampling, one should gather the sample by taking one bottle from each shipping case selected at random. In a sample of 300 bottles this would mean opening that many shipping cases and the labor cost would be high. An intermediate method is suggested as a means of preserving the most of random sampling, and yet reduce the labor of sampling.

The method is as follows:

1. Determine the number of shipping cases and bottles in the lot.
2. Use Mil-Std-105A to determine the number of shipping cases to remove as a sample.
3. Use Mil-Std-105A to determine the number of bottles to examine.
4. Take an equal number of bottles at random from each shipping case until the total sample size for bottles is obtained.

Thus, for a shipment of 700 cases of 24 bottles each (16,800 bottles total) one would enter Table VI-J of 105A and remove a single sample of 75 shipping cases, and according to Table VI-N, would take four bottles from each shipping case for single sampling, three from each case for double sampling, or one from each case for each step in the multiple sampling. By contrast, using random sampling on the basis of one bottle per shipping case, would call for opening 300 of these cases for single sampling, 200 to 600 for double sampling, and of necessity require two bottles from some, and one bottle from the rest of the shipping cases in the entire shipment in the instance of multiple sampling.

In summary, we feel that it has been established that:

1. Sampling of cases from a shipment of glass containers should be at random from the lot, not from one area.
2. Unless the sampler is sure that the production method has not stratified the sample, the entire contents of any one shipping case should not be taken as a part of the sample.
3. In order to decrease sampling costs, a method is proposed of first taking a random sample of the shipping cases, then taking an equal number of bottles at random from each of these cases.

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Control Limits for Visual Quality

ROY B. COWIN, JR.

Kimble Glass Company, Columbus, Ohio

At the time that the procedure for computing control limits for visual defects described in this article was evolved, the author was serving as plant quality control manager for a glass company other than his present employer. This procedure can be used in conjunction with or to supplement the customary procedures for controlling such defects.

In the glass industry, and probably in other allied ceramic industries, many acceptance limits are based on visual intensity samples established as either maximum acceptable or minimum rejectable intensities. In this case, intensity may be defined as the general overall appearance that a defect has on the entire product disregarding such measurable characteristics as location, length, and width. Samples against which the inspectors can frequently check decisions must be readily available and are used on a go, no-go comparative basis. Therefore, it is apparent that these industries have a definite need for control limits for visual defects. This is especially true if quality control is to be applied in the manufacturing departments, the source of the problems, rather than in the sorting (inspecting) and packing departments alone.

Quality control was introduced as a means of controlling the ware released to stock. This was accomplished through the use of the "toll gate" where a quality control check inspector sampled ware selected by the inspection department, releasing satisfactory lots and returning unsatisfactory lots to the inspection department for reinspection.

It soon became apparent that the greatest contribution the quality control department could make was to sample at the time of the forming operation the ware produced by the forming department and to advise the forming operators of the quality of the ware being produced at the forming machine. This was accomplished by assigning a member of the quality control department to relay to the forming operator the findings of a purposive stratified sample, a fixed number of pieces sampled from each position of the machine and selected at definite time intervals.

Having provided a tool to determine the need for action, it was then necessary to build enough reliability into the plan so the operator could take proper action without waiting for the hourly inspection report to be posted as had previously been the case. This was difficult to accomplish as the sorting (inspecting) of the ware lagged production by an hour or more and the inspection center was separated by the length of an annealing furnace (about a hundred feet) from the production station.

An attempt to make the quality control inspector a liaison man between the inspection and forming departments failed. The inspector was unable to move back and forth between the positions and at the same time make his inspections and inspection reports on schedule. Inspection suffered, and an undue amount of ware was rejected at the "toll gate."

It was decided that control limits could be applied to the sampling plan, and instructions for specific action could be given to the quality control inspector when the ware was out of control at the inspection department. The calculation of control limits was based on the inverse solutions of the incomplete Beta-Function as discussed in the *Engineer's Manual of Statistical Methods* by Leslie E. Simon. In particular, we used Chart 0.1 = I_Q and Chart 0.9 = I_Q as follows:

1. The 0.1 and 0.9 I_Q charts were extrapolated so that the curves covered the complete acceptance probabilities from 0.00 to 1.00.
2. A data sheet (Table I) to be provided to each inspector was built up of material extracted from these amended charts:
   a. In our case the sample size selected was one piece per mold (press table position) to be taken two or three times an hour depending upon the nature of the operation, character of product, and other similar factors.
   b. Since the various presses contained 6, 8, 10, or 11 mold positions, the number inspected is a multiple of these numbers and appears across the top of the data sheet.
   c. The left hand headings are the number of good pieces that could be found in the sample.

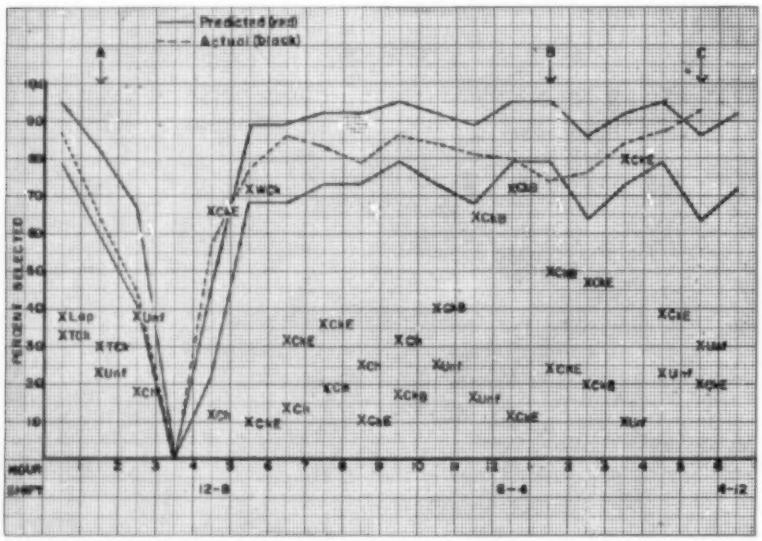

Figure 1

d. The body of the data sheet was built up by taking the chart reciprocals for the chosen situation; i.e., if the number inspected (n) were 22 and there were 16 acceptable pieces (c = 6), Q (I_Q = 0.1 and 0.9) would be 18 and 41 percent and the predicted selected (100% − Q) is 82 and 59 percent. The entire data sheet may be formed by repeating this process substituting the appropriate numbers for n and c.

3. The inspector totals hourly samples and defectives and predicts the hour's percent selection of possible made. This prediction is amended to account for production lost due to machine downtime.

4. Prediction is plotted in red on the appropriate section of the control charts maintained at the forming machine (Fig. 1). For example, if a sample of 22 pieces containing 16 acceptable pieces were inspected between 1:00 and 2:00 A. M., reference to the data sheet of Table I would show that the predicted selection would be between 59 and 82 percent. These points (A on Fig. 1) are plotted on the production section of the control chart and connected in red to the two previously plotted points. The red prediction lines are used as control limits.

5. Percent selected of made is plotted in black by a production recorder on the same chart on which the prediction had been plotted at least one hour earlier.

Although General Simon stresses that random sampling is fundamental in using the I_Q charts, two years' experience has indicated that the purposive sampling discussed earlier in this article has given us satisfactory results for the quality discrimination problem with which we are faced. We do not know, however, to what extent this may nullify the theoretical applicability of the I_Q charts.

To complete the program the following alternatives were open to the quality control inspector:

1. If the percent selected of made fell within the control limits, no action was necessary.
2. If the percent selected of made fell below the lower control limit (B on Fig. 1), the rejects at the inspection area were 100 percent inspected by the quality control inspector for a short interval to ascertain whether the sample he inspected was representative of the lot being made or whether the inspectors were rejecting acceptable ware.
3. If the percent selected of made rose above the upper control limit (C on Fig. 1), the quality control inspector inspected the selected ware to ascertain whether or not rejectable ware was being accepted.

If the quality control inspector found that the inspection department was at fault, he presented

TABLE I—Predicted Selection

$$\text{Predicted} - \left[\frac{(\text{Predicted})\ (\text{Minutes Downtime})}{60}\right] = \text{Corrected Predicted}$$

Number Good	Number Inspected 6	8	10	11	12	16	18	20	22	24	30	33
33												100-94
32												98-89
31												97-85
30											100-93	95-81
29											98-88	93-78
28											96-84	90-75
27											94-80	88-71
26											92-76	85-68
25											89-72	83-65
24										100-91	87-69	80-62
23										98-85	84-65	78-58
22									100-91	95-80	82-61	75-55
21									98-84	93-75	79-58	72-52
20								99-90	95-79	90-71	76-55	70-49
19								97-83	92-73	87-66	73-51	67-46
18							99-89	95-78	89-68	84-62	70-48	64-43
17							97-81	91-71	86-64	80-58	67-45	61-41
16						99-88	94-75	88-66	82-59	77-54	64-42	58-38
15						97-79	91-68	84-61	78-54	73-49	61-39	55-35
14						93-73	87-62	80-55	75-50	70-45	58-36	53-32
13						89-65	83-57	76-50	71-45	66-41	55-33	50-30
12					99-84	85-58	78-51	72-46	67-41	62-38	50-30	48-27
11				99-83	96-73	89-52	74-46	68-41	63-38	59-34	53-27	46-24
10			99-81	95-71	91-64	75-46	69-41	63-37	58-32	55-31	50-24	44-22
9			95-69	90-62	86-56	70-41	64-36	59-32	55-29	52-28	44-21	41-20
8		99-78	89-59	85-53	80-47	65-35	59-32	54-28	51-26	48-24	41-19	38-18
7		94-64	83-49	78-43	73-39	59-31	54-28	50-24	47-22	44-20	39-17	36-16
6	93-73	87-49	77-39	71-36	67-35	54-27	50-23	47-21	43-18	41-16	35-14	33-14
5	92-55	79-40	68-32	64-31	60-30	50-23	46-18	41-17	39-14	38-13	31-12	30-12
4	83-41	70-30	60-27	56-26	53-25	45-18	41-14	37-13	35-11	34-10	29-9	27-9
3	72-28	60-24	51-19	50-19	48-16	40-14	35-10	33-9	32-8	30-7	25-6	24-6
2	60-18	52-18	45-12	43-11	40-11	34-8	30-6	28-5	27-4	26-3	22-3	21-2
1	46-10	45-10	37-5	34-5	34-5	27-2	25-2	24-1	23-0	22-0	19-0	19-0
0	38-4	30-0	29-0	28-0	26-0	21-0	20-0	20-0	19-0	18-0	17-0	16-0

samples as evidence to the inspection foreman, who followed up the problem. If the inspection department was found not to be at fault, the quality control inspector considered his results to be in error and was to exercise greater care in the inspection of his samples.

Thus having provided the operator with an inspection report, a selection forecast, and the actual selection rate, it was deemed advantageous to indicate the magnitude of the major causes for rejection. Hence, each hour the largest two items causing rejects were plotted as their respective percentage of the total rejects and coded. These points could also be cross-referenced with the inspection report of the ware sampled to ascertain the accuracy of the information being forwarded to the machine operator by the quality control inspector. Since the reasons for major rejections can change from hour to hour, these points were not connected as they were for percent predicted and actually selected.

The plant program for the control of visual defects was rounded out by placing a "toll gate" on the flow of rejects from the inspection department to the cullet crusher by either 100 percent inspections or by sampling schemes.

In conclusion, it can be said that the simultaneous use of Leslie Simon's $I_0 = 0.1$ and 0.9 charts may constitute control limits for visual defects in a satisfactory manner that will build reliability into an attribute sampling plan, confidence in quality control inspectors, and accuracy into quality control inspector's work by pointing out differences requiring investigation by him. The forming department will take earlier corrective action, and the inspection department will normally select ware that will flow through the "toll gates" rather than be turned back for reinspection.

What Makes A Quality Control Chart Tick?*

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INTRODUCTION

Most of you are familiar with the working of a control chart which you have gained by experience or by sampling, using beads or tables of random numbers. This knowledge may be made precise and usable by recent discoveries in the theory of control charts.[1]

The purpose of this article is to use the new theory to shed light on the p or sp chart, known as the control chart for fraction defective or number of defectives in the manufacturing process. The results are readily extended to c charts. If you are wedded to 3-σ limits for a control chart and feel that the last word on control charts has been said many times before, this theory may disturb you. Otherwise much might be learned. The new theory is not deep. It is simple, lucid, logical, but nonetheless effective.

THE NEW LOOK

Now what would you like to have a control chart do? "Simple," you say: "If production is in control, all points on the chart should fall within the control limits, and if production is out of control, all points on the chart should fall outside the control limits." But what does a control chart actually do? Four things:

(1) A point may fall within limits — production may be in control; OK, no error

(2) A point may fall outside limits—production may be out of control; OK, no error—the chart tells the truth

(3) A point may fall outside the limits—production is in control; the chart lies—it has made an error.

(4) A point falls within control limits—production is out of control; the chart lies—it has made an error.

Keep these ideas in mind.

Two more ideas. A chart is like a river. It represents a flow of points, or better, production is a flow in time and so is a control chart. We are interested not only in a particular point, but also the points preceding it. Finally, as soon as a point falls outside the control limits, we make the decision that the process is out of control. This is our mode of action. We do not wait for confirmation. We do not wait for another point to fall outside the limits.

A few technical terms need to be introduced. Let p' be the propor-

TABLE 1 — Selected Control Limits and Corresponding Probabilities for Exceeding Them With Three Different Sample Sizes When the Process is in Control at $p' = 0.04$

Sample Size s	Selected Control Limits		Probability of Exceeding Limits α
	Lower	Upper	
25	0	.12	.0165
50	0	.08	.0490
	0	.10	.0144
	0	.12	.00361
200	0	.07	.0152
	0	.08	.00322
	.015	1*	.0125
	.005	1*	.00028
	.015	.07	.0277
	.005	.08	.00350

*UCL = 1 is chosen intentionally to make a one-sided case with α applying to the LCL only.

*Address given at a joint meeting of the American Statistical Association and the American Society for Quality Control, Midwest Regional Group, December 27, 1952 at Chicago, Ill.; and at a joint meeting of the California Section of the Instrument Society of America, and the Los Angeles Section, ASQC, March 13, 1952, at Los Angeles, Calif.; and in a different form at the Middle Atlantic Regional Conference, ASQC, December 2, 1949 at Princeton, New Jersey.

tion of defectives when the process is in statistical control; for example $p' = 0.04$. Each sample of s items drawn from such a binomial distribution gives rise to a point we may call a "decision point" which is plotted on the control chart. The proportion defective in each sample we denote by p. The probability of having a point fall outside the control limits at exactly the N-th decision point when the process is in control at the level p' is $\alpha(1-\alpha)^{N-1}$, where α is the probability of a point falling outside the control limits at a single decision point. Now α is determined as soon as we decide on the control limits. It is completely at our disposal; if we change the control limits, then α changes also. The probability of stopping production at the N-th decision point or sooner turns out to be given by $1-(1-\alpha)^N$. This we call the *complete stoppage spacing function*, since production is stopped needlessly, as we are assuming that the process is in control. The average value of N

TABLE III — Complete Stoppage Spacing Function (CSSF)

Probability of a point falling outside control limits by chance alone in N or fewer decision points for three of the cases listed in Table I.

(See also Figs. 1-4)

N	s = 25 α = .0165 1/α = 60.6	s = 50 α = .049 1/α = 20.4	s = 50 α = .00361 1/α = 277
1	.0165	.049	.00361
2	.033	.096	.0072
3	.049	.140	.0108
4	.064	.182	.0144
5	.080	.222	.0179
6	.095	.260	.0215
7	.110	.296	.0250
8	.125	.331	.0285
9	.139	.364	.0320
10	.153	.395	.0355
11	.167	.424	.0390
12	.181	.453	.0425
13	.195	.479	.0459
14	.208	.505	.0494
15	.221	.529	.0528
16	.234	.552	.0562
17	.246	.574	.0596
18	.259	.595	.0630
19	.271	.615	.0664
20	.283	.634	.0698
21	.295	.652	.0731
22	.307	.669	.0765

Consider the 0.153 entry in row N = 10, column s = 25, $\alpha = 0.0165$. This is obtained as follows:

$$\begin{aligned} \text{CSSF} &= 1-(1-\alpha)^N = 1-(1-0.0165)^{10} \\ &= 1-(0.9835)^{10} \\ &= 1-0.847 = 0.153 \end{aligned}$$

For this case, Table I gives UCL = 0.12. Thus, for a process operating in control at $p' = 0.04$ with UCL = 0.12, the chance is 0.153 that stoppage will mistakenly occur within ten successive samples of size 25 by having a sample p-value plot beyond the UCL = 0.12.

TABLE II — Power Functions

Values of γ for Fixed s and α Values and Variable p' Values*

p'	s = 25	s = 50			s = 200					
	α = .0165	α = .0490	α = .0144	α = .0036	α = .0152	α = .00322	α = .0125	α = .00028	α = .0277	α = .00350
.00	0	0	0	0	0	0	1.0000	1.	1.	1.
.01	.00011	.000146	.0000109	.0000007	0	0	.677	.134	.677	.134
.02	.00145	.003210	.000478	.0000601	.00001	0	.235	.018	.235	.0176
.03	.00619	.0168	.00374	.000704	.0012	.0002	.059	.0023	.061	.0025
.04	.0165	.0490	.0144	.00361	.0152	.00322	.0125	.00028	.0277	.00350
.05	.0341	.1036	.0378	.0118	.078	.024	.002	.00004	.081	.024
.06	.0598	.1794	.0776	.0289	.222	.095	.0004	.000004	.223	.095
.07	.0936	.2710	.1350	.0583	.430	.238	.00006	.0000005	.430	.238
.08	.1351	.3710	.2081	.1019	.640	.434			.640	.434
.09	.1831	.4723	.2928	.1596	.804	.633			.804	.633
.10	.2364	.5688	.3839	.2298	.907	.793			.907	.793
.11	.2934	.6562	.4760	.3091	.961	.897			.961	.897
.12	.3525	.7320	.5647	.3935	.985	.954			.985	.954
.13	.4123	.7956	.6463	.4789	.995	.982			.995	.981
.14	.4714	.8472	.7186	.5616	.998	.993			.998	.993
.15	.5289	.8879	.7806	.6387	.9995	.998			.9995	.998
.16	.5837	.9192	.8323	.7081		.9993				
.17	.6352	.9428	.8741	.7686						
.18	.6829	.9601	.9071	.8199	1.000000	.99994				
.19	.7266	.9726	.9327	.8624						
.20	.7660	.9815	.9520	.8966		.999996				
.21	.8013	.9877	.9663	.9236						
.22	.8324	.9919	.9767	.9445						
.23	.8593	.9948	.9841	.9603						
.24	.8834	.9967	.9893	.9720						
.25	.9038	.9979	.9930	.9806						
.26	.9211									
.27	.9358									
.28	.9481									
.29	.9583									
.30	.9668									
.31	.9737									
.32	.9792									
.33	.9838									
.34	.9874									
.35	.9903									
.36	.9926									
.37	.9943									

*Entries in this table show values of γ = probability of a point falling outside control limits that have been set as shown in Table I. For example, in the s = 50, $\alpha = 0.0036$ column, we have a chart set up for $p' = 0.04$ with UCL = 0.12, α 0.0036. If, now, a sample of 50 is taken from a process for which p' is actually at 0.15 rather than at 0.04, then the probability of getting a sample value of p that will plot *beyond* the established UCL = 0.12 is shown to be $\gamma = 0.6387$.

TABLE IV—Complete Effectiveness Function (CEF)
Alternative $p_1' = 0.08$

(See also Fig. 1)

N	s = 25	s = 50			s = 200	
	α = .0165	α = .049	α = .0144	α = .0036	α = .0152	α = .00322
1	.135	.371	.298	.102	.642	.434
2	.252	.604	.373	.193	.871	.680
3	.353	.751	.503	.276	.953	.819
4	.440	.844	.607	.349	.983	.897
5	.516	.902	.687	.416	.994	.942
6	.581	.938	.753	.475	.998	.967
7	.638	.961	.805	.529		.981
8	.689	.976	.845	.577		.989
9	.729	.985	.878	.620		.994
10	.766	.991	.903	.659		
11	.797		.923	.693		
12	.825		.939	.725		
13	.848		.952	.753		
14	.869		.962	.778		
15	.887		.970	.800		
16	.902		.976	.821		
17	.915		.981	.839		
18	.927			.855		
19	.937			.870		
20	.945			.883		
21	.953			.895		
22	.959			.906		
23	.965			.916		
24	.969			.924		
25	.973			.932		

Consider the 0.659 entry in row N = 10, column s = 50, α = 0.0036. This is obtained as follows: in Table II, row p′ = 0.08, column s = 50, α = 0.0036, we find γ = 0.1019. Then

$$\begin{aligned} \text{CEF} &= 1 - (1 - \gamma)^N \\ &= 1 - (1 - 0.1019)^{10} \\ &= 1 - (0.8981)^{10} \\ &= 1 - 0.3414 \\ &= 0.659 \end{aligned}$$

For this case Table I gives UCL = 0.12. Thus, for a chart set up for p′ = 0.04 with UCL = 0.12, the chance is 0.659 that if the process level has shifted to 0.08 it will be caught within ten plottings after the shift by having a sample p-value fall beyond 0.12, sample size being 50.

TABLE V—Complete Effectiveness Function (CEF)
Erratic Production
$p_1' = 0.03, 0.05, 0.03, 0.05$, repeated

(See also Fig. 2)

N	s = 25	s = 50			s = 200	
	α = .0165	α = .0036	α = .0144	α = .049	α = .015 One-sided	α = .028 Two-sided
1	.0062	.0007	.0037	.017	.00145	.061
2	.040	.012	.041	.119	.080	.137
3	.046	.013	.045	.134	.081	.189
4	.079	.025-	.081	.223	.153	.254
5	.084	.025+	.084	.236	.155	.300
6	.115	.037	.119	.315	.232	.356
7	.121	.038	.122	.327	.233	.395
8	.151	.049	.155	.397	.294	.444
9	.156	.050	.159	.407	.295	.478
10	.185	.061	.190	.468	.352-	.520
11	.190	.062	.193	.477	.352+	.549
12	.218	.073-	.224	.531	.404	.586
13	.222	.073+	.227	.539	.405	.611
14	.249	.084	.256	.587	.453	.642
15	.254	.085	.259	.593	.454	.664
16	.279	.096-	.287	.636	.497	.691
17	.284	.096+	.289	.642	.498	.710
18	.308	.107	.315	.679	.539-	.733
19	.312	.108	.318	.685	.539+	.749
20	.336	.118	.342	.717	.576	.770
21	.340	.119	.345	.722	.577	.784

Consider the 0.236 entry in row N = 5, column s = 50, α = 0.049. This is obtained as follows: In Table II, column s = 50, α = 0.049 we find for p′ = 0.03 that γ = 0.0168, and for p′ = 0.05, γ = 0.1036. Then

$$\begin{aligned} \text{CEF} &= 1 - (1 - 0.0168)\ (1 - 0.1036)\ (1 - 0.0168)\ (1 - 0.1036)\ (1 - 0.0168) \\ &= 1 - (1 - 0.0168)^3\ (1 - 0.1036)^2 \\ &= 1 - (0.9832)^3\ (0.8964)^2 \\ &= 1 - 0.7637 \\ &= 0.236 \end{aligned}$$

Table I gives UCL = 0.08 for this case. Thus, for a process operating against standards of p′ = 0.04, UCL = 0.08 but for which the process level oscillates from levels of 0.03 to 0.05 to 0.03, etc. at successive samplings, the chance is 0.236 that it will be caught within five plottings by having a sample p-value fall beyond 0.08, sample size being 50.

is simply 1/α, so we see that if nothing else mattered we would make α very small, say 0.001, and then we would stop production needlessly on the average every 1000 decision points. The choice of α depends however on what the alternative is to a process in control. A process may be out of control in many ways.

If the process is out of control because it is operating at a new, constant level p_1', then we would like to stop the process as soon as it is uneconomical to produce at the level p_1'. The function, which corresponds to the complete stoppage spacing function, we call the *complete effectiveness function*, and it is given by $1 - (1 - \gamma)^N$, where γ is the probability of a point falling outside the control limits set up for p′ when actually the process is at level p_1', and N is the number of decision points taken while production is at the level p_1'. The average value of N in this case is simply $1/\gamma$. Ordinarily one might desire to make γ a value close to one, but this has two disadvantages. The sample size s may need to be large. Further, it may not be important to catch this shift from p′ to p_1' on the first decision point after the change in production, but on the second, or on the third, since samples will be taken regularly in any case. If you fail at first, try try again.

Now production may also be out of control because it is at a different level of p_1' at *each* decision point. The complete stoppage spacing function remains as before, but the complete effectiveness function is

$$1 - (1 - \gamma_1)\ (1 - \gamma_2) \ldots (1 - \gamma_N),$$

where γ_i is the probability at the i-th decision point of a point falling outside the p′ control limits when production is at the level p_1 and not p′. In this case there exists no simple general formula for the average value of N, although in any particular case the mean and median of N are readily determined.

Let's try out the theory for a few cases. Suppose the alternative to $p' = 0.04$ is $p_1' = 0.08$. How many decision points need to be taken on the average for the control chart to tell us that production is not at a level p′ = 0.04? The answer of course is $1/\gamma$. But γ depends on the value of α and the size of the sample s. If α is small, γ tends to be small for the same sample size s; and if s is large, γ tends to be closer to one

for a fixed α. Further, let us say when $p' = 0.04$, we want the average value of N to be 50. This makes $\alpha = 0.02$. And let us suppose when $p_1' = 0.08$, we want the average value of N to be 5. This makes $\gamma = 0.20$. Given γ and α we should be able to find s, which we assume constant from decision point to decision point. We must solve the two equations

$$\sum_{x=r+1}^{s} {}_sC_x\ (0.04)^x\ (0.96)^{s-x} = \alpha = 0.02 \quad (1)$$

and

$$\sum_{x=r+1}^{s} {}_sC_x\ (0.08)^x\ (0.92)^{s-x} = \gamma = 0.20 \quad (2)$$

for r and s. Of course r/s will be the upper control limit for the control chart with $p' = 0.04$.* From the table of the binomial distribution[12] we find $s = 39$, $r = 4$, with $\alpha = 0.019$ and $\gamma = 0.199$, which may be considered satisfactory. This demonstrates one use of the formulas, but it seems more desirable and just as easy to choose an s and an α, find the control limits and γ, and plot the complete stoppage spacing and the complete effectiveness functions.

In order to cover an informative range of possibilities, we take s = 25, 50 and 200, and a selection of values of α corresponding to different control limits. For the alternatives besides $p_1' = 0.08$ we take $p_1' = 0.03, 0.05, 0.03, 0.05$, etc.—a rather difficult case since the average value is still 0.04; $p_1' = 0.01, 0.02, 0.03, 0.04$, etc.—an increasing proportion of defectives; $p_1' = 0.05, 0.06, 0.08, 0.02, 0.04, 0.09, 0.03, 0.10, 0.04$ and then this set repeated indefinitely—a case we call chaotic production. For the largest size sample, s = 200, we are able to have two-sided limits, both upper and lower, for p, the percentage defective in the sample. For convenience, control limits and the corresponding values of α are listed in Table I. In constructing the table, it was assumed that a point falling exactly on the control limits would be interpreted to mean that the process is in control.

It is evident that for a given s not all values of α are possible. For example, with s = 25, $p' = 0.04$, possible control limits are 0 — 0.04 which makes $\alpha = 0.264$; 0 — 0.08 with

*This is so because the summation in (1) gives the probability of getting more than r defectives in a sample of size s, and hence of getting a p-value greater than r/s. We have here set the risk of exceeding this value of p at $\alpha = .02$, so it would be appropriate to call this an upper control limit although clearly it is not the usual 3σ limit.

TABLE VI—Complete Effectiveness Function (CEF)
Increasing Trend
$p_1' = 0.01, 0.02, 0.03, 0.04, 0.05$, etc.

(See also Fig. 3)

N	s = 25	s = 50		s = 200
	α = .0165	α = .0036	α = .014	α = .028 Two-sided
1	.00011	0	0	.678
2	.0016	.0006	.003	.753
3	.0077	.0008	.020	.768
4	.0241	.0044	.068	.774
5	.057	.016	.165	.793
6	.114	.045	.315	.839
7	.197	.100	.500	.908
8	.305	.192	.686	.967
9	.432	.321	.834	.994
10	.567	.477	.928	.999
11	.694	.639	.975	.99998
12	.802	.781	.993	
13	.883	.895	.997	
14	.938	.954	.998	
15	.971	.983		
16	.988	.995		
17	.996			
18	.999			
19	.9996			

Consider the 0.793 entry in row N = 5, column s = 200, $\alpha = 0.028$. This is obtained as follows: in Table II, column s = 200, $\alpha = 0.0277$, we find for p′ running from 0.01 through 0.05 the γ values 0.677, 0.235, 0.061, 0.0277, and 0.081. Then

$$\begin{aligned} \text{CEF} &= 1 - (1 - 0.677)(1 - 0.235)(1 - 0.061)(1 - 0.0277)(1 - 0.081) \\ &= 1 - (0.323)(0.765)(0.939)(0.9723)(0.919) \\ &= 1 - 0.207 \\ &= 0.793 \end{aligned}$$

Table I gives LCL = 0.01, UCL = 0.07 for this case. Thus, for a process operating against standards of $p' = 0.04$, LCL = 0.01, UCL = 0.07, but for which the process level runs from 0.01 through 0.05 on five successive samplings, the chance is 0.793 that it will be caught within five plottings of the first shift to the 0.01 level by having a p-value fall either below 0.01 or beyond 0.07, sample size being 50.

TABLE VII—Complete Effectiveness Function (CEF)
Chaotic Periodic
$p_1' = 0.05, 0.06, 0.08, 0.02, 0.04, 0.09, 0.03, 0.10, 0.04$, repeat

(See also Fig. 4)

N	s = 50				s = 200		
	α = .0165	α = .0036	α = .014	α = .049	α = .0032 One-sided	α = .0152 One-sided	α = .028 Two-sided
1	.034	.012	.038	.104	.024	.078	.081
2	.092	.040	.113	.264	.117	.283	.285
3	.215	.138	.298	.537	.500	.742	.743
4	.216	.138	.299	.539	.500	.742	.803
5	.229	.141	.309	.561	.502	.746	.809
6	.370	.278	.512	.769	.817	.959	.963
7	.374	.278	.513	.773	.817	.950	.985
8	.522	.446	.701	.902	.962	.995	.997
9	.530	.447	.705	.907	.963	.995	.997
10	.546	.453	.716	.917	.966	.996	
11	.573	.469	.738	.933	.981	.996	
12	.631	.522	.793	.958	.981		
13	.631	.522	.793	.958	.982		
14	.637	.524	.796	.960	.993		
15	.704	.599	.856	.980			
16	.705	.599	.857	.980			
17	.775	.690	.912	.992			
18	.779	.691	.914	.993			
19	.786	.695	.917	.994			
20	.799	.703	.924	.995			
21	.825	.733	.940	.997			

Consider the 0.309 entry in row N = 5, column s = 50, $\alpha = 0.014$. This is obtained as follows: in Table II, column s = 50, $\alpha = 0.0144$, the γ values that go with the p′ sequence 0.05, 0.06, 0.08, 0.02, 0.04 are respectively 0.0378, 0.0776, 0.2081, 0.000478, and 0.0144. Then

$$\begin{aligned} \text{CEF} &= 1 - (1 - 0.0378)(1 - 0.0776)(1 - 0.2081)(1 - 0.000478)(1 - 0.0144) \\ &= 1 - (0.9622)(0.9224)(0.7919)(0.99952)(0.9856) \\ &= 1 - 0.691 \\ &= 0.309 \end{aligned}$$

Table I gives UCL = 0.10 for this case. Thus, for a process operating against standards of $p' = 0.04$, UCL = 0.10, but for which the process level follows the p′ sequence listed above over five successive samplings, the chance is 0.309 that it will be caught within five plottings of the first shift to the 0.05 level by having a p-value fall beyond the UCL = 0.10 line, sample size being 50.

$\alpha = 0.076$; $0 - 0.12$ with $\alpha = 0.0165$; $0 - 0.16$ with $\alpha = 0.00278$; $0 - 0.20$ with $\alpha = 0.000376$, etc. Now if one had in mind an $\alpha = 0.01$, he would have to be satisfied with $0 - 0.12$ and $\alpha = 0.0165$; or if he had in mind an $\alpha = 0.001$, he would have to be satisfied with $0 - 0.16$ and $\alpha = 0.00278$.

To find the values of γ, we must determine the probability of a point falling outside the control limits given in Table I for a process operating against the standard $p' = 0.04$. This is given in Table II. You may find it worthwhile to graph the power function γ as a function of p'. Of course, one minus the power function is the well known operating characteristic curve of a control chart.

Table III lists the values of the complete stoppage spacing function for three of the cases given in Table I. The complete effectiveness functions for the various alternatives are listed in Tables IV-VII and shown on the graphs in Figs. 1-4. It should be noted that the complete stoppage spacing function (also shown in Figs. 1-4) depends essentially on α and not on s, so the cases tabulated cover a practical range.

COMMENTS AND CONCLUSIONS

A study of the graphs will prove rewarding. It seems unnecessary to go into any extended discussion. Four conclusions should be stressed:

(1) Both the complete stoppage spacing function and the complete effectiveness function are extremely sensitive to small changes in α. It is not enough to say α is approximately 0.01 and contend that the complete effectiveness function for $s = 50$, $\alpha = 0.0036$, and for $s = 50$, $\alpha = 0.014$, with $p_1' = 0.08$, are the same. Too much of this erroneous type of reasoning has crept into the literature of quality control. A glance at Fig. 1 shows how far apart the two complete effectiveness functions are.

(2) For those who only incidentally or infrequently use control charts, the usual 3-σ limits will prove adequate. Where many charts are used, or a single chart over and over again, the new theory is far superior and worth the extra trouble and thinking.

(3) It is worthwhile to make a careful analysis of the control charts you may be using at present for attributes. Undoubtedly you will discover ways of improving their

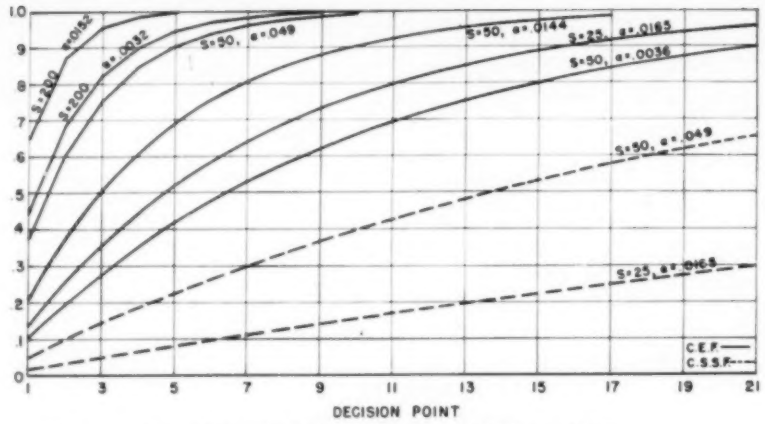

Figure 1 — Complete Effectiveness Function (CEF) and Complete Stoppage Spacing Function (CSSF)

Simple Alternative: $p' = 0.04$, $p_1' = 0.08$

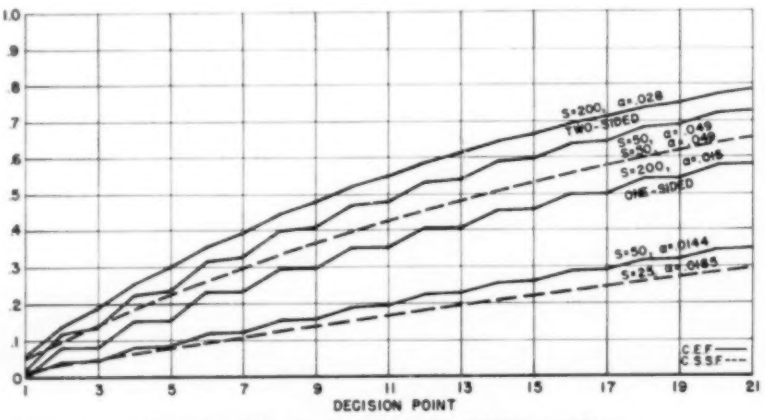

Figure 2 — Complete Effectiveness Function (CEF) and Complete Stoppage Spacing Function (CSSF)

Erratic Production: $p' = 0.04$, $p_1' = 0.03, 0.05, 0.03, 0.05$, etc.

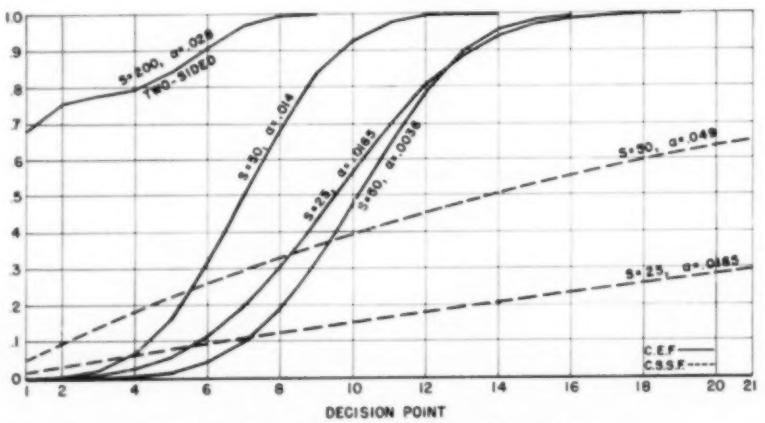

Figure 3 — Complete Effectiveness Function (CEF) and Complete Stoppage Spacing Function (CSSF)

Increasing Trend: $p' = 0.04$, $p_1' = 0.01, 0.02, 0.03, 0.04, 0.05$, etc.

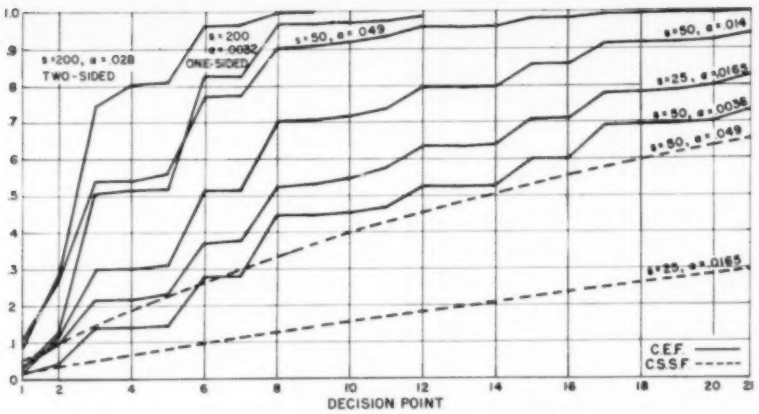

Figure 4 — Complete Effectiveness Function (CEF) and Complete Stoppage Spacing Function

Chaotic Production: $p_0' = 0.04$
$p_1' = 0.05, 0.06, 0.08, 0.02, 0.04, 0.09$
0.03, 0.10, 0.04, repeat periodically

effectiveness by analyzing the particular process being controlled, and the economic costs associated with the complete stoppage spacing and the complete effectiveness functions.

(4) Take the case of increasing trend in Fig. 3. If we use the two-sided test $s = 200$, $a = 0.028$, we would stop the process very soon, frequently at the first decision point. However if we stopped at the first decision point we might try to see why p_1' is so low, when actually what would be more desirable would be to see the trend on the control chart and then attempt to see why the process involved this trend. In such a case it is preferable to use a one-sided test instead of a two-sided test.

ACKNOWLEDGEMENT

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Editorial Note: The reader may find "The Frequency of Selecting Samples for Attribute Testing," A. C. Cohen, Jr., *Industrial Quality Control*, Volume VIII, No. 1, July 1951, p. 32, a useful companion paper to this one.

Quality Control Techniques for Electronic Components*

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INTRODUCTION

The wide-spread demand for electronic equipment in the last few years has resulted in a mushroom growth of a large number of both new and old firms. Small companies were hastily formed to supply this demand when it was found that many concerns would have to reduce their production due to electronic shortages caused by defense needs. Those able to obtain financial sponsors have spread their skills over a myriad of electronic components. New techniques sponsored by quality control have played an important role in these developments. However, in many plants the role of quality control has been very minor due to a lack of understanding of its objectives.

The term "quality control" has been used to cover a wide variety of activities, many related only indirectly with quality. This is to be expected since the government has demanded that satisfactory and adequate quality control systems be installed in all plants from which the various agencies purchase material. Quality control groups have sprung up in different spots in manufacturing organizations with widely different functions. Some assist engineering and developmental departments in their qualification tests and product engineering activities. Others merely inspect, take little or no data, and wonder why they generate vast quantities of paper work but do not improve the quality of outgoing product. A clearer understanding of the objectives will indicate why the application of certain techniques results in improved outgoing quality at a reduced cost.

OBJECTIVES OF QUALITY CONTROL

The more complicated electronics equipment is often sold as a system. Each system consists of a large number of units. These units are made up from assemblies and subassemblies. So-called spares consist of a group of units generally, and are often given a final test using sufficient units to make up a system as the test equipment equivalent. The excess units are then removed so that only such units as are required

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†At the time of writing this article Dr. Romig was with Hughes Aircraft Co.

are combined to make up the desired spare. The set-up is similar to switchboards, where a completed board may be fully or partially equipped. Many of the techniques used on switchboards apply equally well to other types of electronic equipment.

In the manufacture of such electronic equipment, quality must be built into the product all along the line. Eternal vigilance is required to see that even minor items of workmanship, which later may be hidden in the maze of wiring and apparatus, are of a satisfactory nature in line with standards of good workmanship. Manufacturing is responsible for the quality of the equipment produced. It provides testers and checkers wherever it is felt that a check must be made in order to prevent the addition of a large amount of costly work to a subassembly or component when a small amount of inspection and test effort will prevent substandard parts from being used. Such controls may be thought of as functional controls. When manufacturing, at each production sequence, feels that the component under consideration is unsatisfactory it is turned back for re-work and change by the manufacturing section.

Quality control groups, divisional and central, work cooperatively with manufacturing to assist it to control each step of the process with minimum cost. Errors in measurements may creep in unless quality control applies controls that assure proper calibrations of all test apparatus and testing equipment. Quality control must analyze all inspection and test results that have meaning and make such auxiliary inspections and tests as may be required for verifying manufacturing's inspection results.

It is impossible in this limited article to describe all the steps and techniques that should be applied in manufacturing the best possible electronic equipment. A few concrete cases will indicate the measures that are necessary. These may be modified in other plants in line with the peculiar needs of each particular manufacturer. Also, recognition must be given to the role that quality control must play in the original design, qualification tests, type tests, trials, and ultimately in the manufacturing process itself.

QUALITY CONTROL IN DESIGN

When an objective has been set and engineers and research men are requested to make a new product, it first appears that the job is one that should be confined to the research and design engineers. This is a mistaken notion which will hamper future production and slow down the program. When the research engineer has a new idea to check, it is necessary that he not only check his theoretical concepts with able mathematicians and physicists but also that he check the ability to reproduce the unit and associated data under production conditions. A tailor-made product is a work of art and those connected with its development are unhappy when they find that it cannot be made practicably with the same fine care that the research and development engineers apply in their studies. Drawing board models are extremely valuable. Checks made on prototypes indicate the nature of the discrepancies and what corrective action is required.

Here is where the most careful use should be made of the various theories of small lot sizes and samples. The data are meager but rich in potential possibilities. The research and development engineers should discuss their early problems with qualified personnel in the quality control groups. Steps should be taken to have the required data obtained according to a prescribed design, such as a Latin square or a factorial design. When the data are secured, the statistician assists the engineer in the analysis so that all the information contained therein may be summarized. From such information it will be possible to establish a design that is practical and also to set tolerances that can be met in production.

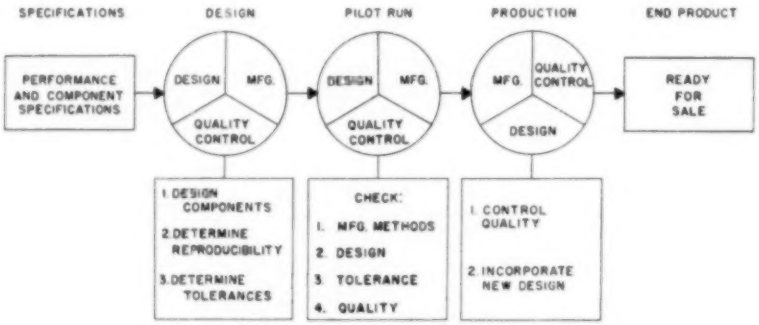

Figure 1—Quality Control in Production

QUALITY CONTROL IN MANUFACTURING

After the design has been initially established, the next step is to set up qualification tests for the product as a whole. The requirements of service may be severe requiring the product to function properly over a wide range of temperatures, high humidity and shock. The necessary tests must next be set up. It is not enough to have the specification spell out the objectives. These must now be set forth in a Test Specification. This test specification must indicate all the tests that are needed in order to insure that the equipment will function properly alone or as a part of a larger unit. In this connection it may be necessary to set up regular periodic tests to determine that in subsequent manufacturing the product will continue to be satisfactory. The amount of testing required appears at first to be purely an engineering problem.

However, it is again desirable for the team consisting of the development engineer and the quality control engineer to collaborate and write out explicitly how much information is required periodically. With this information a complete testing program can then be set up. The number and nature of the tests must be tabulated and at times even incorporated in the specification or contract. Some tests will require very expensive testing equipment. Also, some tests may be destructive in nature and require extra units to be taken from the line at random as representative of the process. When set up properly, suitable controls will be established so that it can readily be determined whether the process remains in statistical control.

These techniques precede the regular production runs, although the type test may be run in conjunction with production as time goes on to maintain continued control. Pilot runs are highly desirable. In many instances, due to an immediate demand for the product, the pilot-run phase of the operation is dropped. This is unfortunate as it precludes the elimination of a lot of undesirable features that arise in production when it is found that the design which was satisfactory for research and development purposes cannot be made in quantity. Hence slight changes in the design must be made to permit continuous production at a reasonable rate.

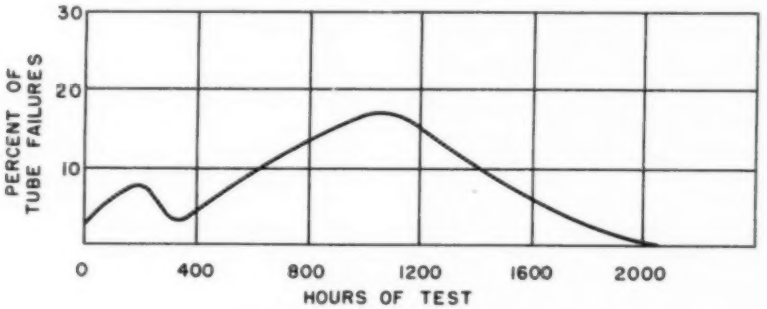

Figure 2—Vacuum Tube Life Expectancy

Two other factors need to be considered: (1) Life and (2) Ease of Maintenance. While the product is being qualified, it will be necessary to have some units on life test. If enough information is available, such life tests may in many cases, be accelerated. This is highly desirable as it indicates early in the production process the inherent weakness in the product resulting from design or the particular manufacturing process. In many instances, however, there has been found no accelerated substitute for the normal life test under standard operating conditions.

LIFE TEST TECHNIQUES

Consider the nature of the life test data required for a vacuum tube. First, a sufficient sample must be taken, say 25, so that the final results of the life test will provide both an indication of level, or central tendency, and an indication of spread or variability. For the key characteristics for a particular type tube, readings must be taken at sufficient time intervals to provide a fairly accurate picture as to what may happen. In some instances the development engineer must know the increase in variability that results from having intermittent operation rather than continuous operation. Preferably, a form should be provided to record the readings at the intervals desired. In this connection it is well to consider the working hours of the technicians making the readings so that the observations will be obtained during regular working hours.

The distribution for many types of vacuum tubes is essentially bi-modal with respect to life. It has been found that the early failures are usually due to mechanical difficulties whereas the failures that occur later are primarily electrical. In order to obtain a true picture for any given type, a preliminary run should be made to indicate how frequently readings should be taken in order to obtain this bi-modal curve, particularly in the early part of the test. If readings are not obtained at short enough intervals, unless an automatic recorder has been used, the exact time of the early failures will not be known. With some of the more stable tubes the time interval between readings may be very long. This is true if the expected life of the particular tube type is 5000 hours or more. If, however, the expected life is 500 hours or less, readings will have to be taken much more frequently. Vacuum tubes have to be tested under standard operating conditions, as, so far, no real means that has any meaning has been obtained for accelerating their life. With capacitors, on the other hand, accelerated life tests may be used with a reasonable degree of success.

The problem next arises—How can one determine from the early readings and failures whether the lot of tubes from which the sample was taken is satisfactory for release for shipment? A life test is being run with, say, 25 tubes on life test. The expected life is 800 hours. After 200 hours on test, three of the tubes have failed. Should the lot be accepted, rejected or be suspended until additional data on these 25 tubes have been obtained? Several papers on this subject have been published.[1] None of them gives the exact solution, but they do assist one in formulating the problem.

In all kinds of tests that require a long time to make, such as many environmental tests, the question arises: How long shall a lot be held before release? Until the tests are completed? This is the most desirable, but that may mean at least one month or possibly six months. The problem of storage space confronts all manufacturers if all units are to be held until these long tests are completed. It is not unusual to require 1000 hour tests. Now a month of 30 days contains only 720 hours so that a 1000-hour test means about 1½ months holding period. To many it appears reasonable to release the lot for shipment if no failures occur in the first 48 hours and the readings are satisfactory. What risks are being taken? The answers to such questions require prior analysis of comparable data. Since such data are not usually available in large quantities in a single company, the pooling of such information by associations representing large numbers of manufacturers, such as the Radio-Electronics-Television Manufacturers Association (RETMA), is highly desirable.

CLASSIFYING DEFECTS

The majority of the tests, or at least inspections for dimensions, color, appearance, materials and workmanship, are done by attributes inspections. One of the techniques that is often important is to properly classify the items being checked as to their importance. This leads to a weighted value, often expressed in terms of Demerits or Demerits-per-Unit. If this procedure is to be followed, then a Classification of Defects is required. Possibly the better term is a Classification of Inspection Items with respect to their importance in line with certain

clear-cut definitions as to the method used in the classification. Four-fold classifications are the most popular. Often such a classification results in essentially a three-fold or sometimes even only one classification. The military use the terms: (1) Critical, (2) Major, (3) Minor, and (4) Incidental. Using the published definitions, [2] it is possible to properly evaluate all the requirements with respect to their importance.

There are some that oppose any classification of defects. Their argument is that all requirements must be satisfied. If even an Incidental Inspection Item is not met, then steps should be taken to eliminate this situation and each inspection item should be considered equally important. Analyzing each item, its application and function in accordance with its specification and specifically per the appropriate drawing, then a conclusion may be reached as to the advisability of using a weighting system. Many articles on rating [3] cover this point to a degree. More research is required on this subject in order to properly evaluate it. The use of weighting values should be carefully considered. Where many components enter a final rate, use may be made of the notion of using weights based on experience, demand, maintenance costs or even initial costs. There are many border line cases where fraction defective is not too good a measure of quality. Careful judgment is required to incorporate the proper system in any well organized quality control program.

ACCUMULATED TOLERANCES

The quality control engineer should assist the design engineer in determining over-all tolerances. At first this appears to be an easy task from the manufacturing point of view, where it is possible to obtain large quantities of data upon which the tolerances may be based. The design engineer readily determines from theoretical considerations whether the tolerances arrived at from the data are reasonable. Often, however, the theoretical design demands a very rigid tolerance which cannot possibly be met. If this is the case, then it is necessary to study the distributions of the various components and determine the contribution of each to the over-all variability. Where the distribution is essentially linear, then it is possible to arrive at a quick solution based on a random distribution. Adding the variances of the components may provide a fairly close estimate of the over-all variance under the above conditions. Squaring the component tolerances and adding them gives a theoretical value for the square of the over-all tolerance. This procedure is based on the theorem concerning the addition of variances where the variance is the standard deviation, σ, squared, and the standard deviation is the root mean square of the deviations about the arithmetic mean of the data involved.

The simple procedure above for obtaining over-all tolerances is satisfactory for the majority of cases. When the distributions are such that the contribution of the components is not linear, due not only to the nature of the various characteristics but also to the mathematical relation that represents the resultant effect of the various contributory variables, the over-all variance is more difficult to determine accurately. For example, for three characteristics x, y and z, it is found that they may be combined as products, quotients, sums and/or differences. Thus the value xy/z consists of a product divided by the third variable. The theory of the propagation of error [4] covers this combination, but not directly. If full advantage is taken of the second- and even third-order effects that are evidenced by the form taken by the relation covering the over-all effect of all inspection items, a fairly good estimate of the variability may be obtained. In some instances, however, it is not necessary to know the over-all tolerance. Control is obtained much easier if it is exercised over the individual components. When the effect on the whole of each individual item is noted, then it is possible to determine how well the over-all product is controlled. Sometimes this is a little difficult at first, for it may be almost impossible to measure some of the items that contribute to the final result. Indirect methods of measuring or testing may be developed that supply the necessary information for obtaining the control desired.

It is not necessary in many cases to keep perpetual watch over all components. Some inherently remain in control. To achieve a tight control only the most important items need to be charted. When something starts going wrong in the process then it is the duty of Central Quality Control to account for the discrepancy as quickly as possible and have the proper authority instigate remedial action. This responsibility covers a wide range of possible troubles. A thorough knowledge of the process is required in order to properly evaluate the trouble and seek intelligently for an answer. When things start to go wrong, and before many pieces are produced, action should be taken to prevent a recurrence of the trouble. Preventive measures are always best. In many plants the fallacy of only looking at the end product is followed. This causes the quality control inspectors to be mere screeners and destroys their initiative. Truly controlling the process by the judicious use of charts, tables and graphs, and taking action when required will make other groups anxious to apply quality control procedures. Careful inspection of a small sample from each lot will not only give an Acceptance-Rejection Plan that provides excellent protection, but it also affords an opportunity to apply control techniques to the inspection results and take action at the first indication of an unsatisfactory change in the process.

VARIETY OF TECHNIQUES AVAILABLE

Electronic apparatus and equipment vary so much that it is necessary to use a variety of techniques in controlling their quality. Fundamentally, quality must be built into each unit. If the product is simple in nature with very few requirements, it is possible to check only one or two key requirements and determine both the acceptance of the current lots and the ability of the product to meet its quality standards. One technique that has been used to a great extent in receiving inspection is the lot plot [5] system of inspection which is usually applied to the key characteristics. This system requires the recording of each measurement in a sample of 50 units, taking them in sets of five each. An estimate of the standard deviation based on the ranges is derived from $\bar{R}$ and the d_2 factor. Three sigma control limits then are determined from the relation $\bar{X} \pm 3\bar{R}/d_2$ and if these values are well within the tolerance limits and

if the distribution of the 50 observations appears to be such that practically no units are outside the engineering requirements, the lot is accepted. If, however, the above conditions are not met, the lot may be rejected if it is very apparent that there will be a considerable portion of the product outside the specified limits. In questionable cases the distribution of the 50 observations is studied carefully and additional inspection by the method of attributes may be applied.

The procedure for the lot plot system is sometimes deemed to lack the sensitivity required for discrimination against unsatisfactory product and additional criteria are needed. Even the use of templates, presenting different possible satisfactory and unsatisfactory distributions, is not sufficient to determine acceptance or rejection of the lot for many observed distributions obtained from the 50 recorded values taken from the lot. A control chart for the averages of the ten subsamples and also in some cases for the ten ranges is used and often proves a valuable adjunct for determining whether the lot shall be accepted or rejected. The evaluation of such control charts for subsamples of five each, depends on whether the lot in question is one in a series of lots of similar product or is the only lot of its kind. If one of a series, then analysis of prior data from similar lots may be used to provide fairly good estimates of $\bar{X}'$ σ', and R'. If the 50 measurements are all the data available, consideration should be given to the number of each statistic, $\bar{X}$, σ, or R that fall within 1σ limits, 1.5σ limits, 2σ limits and 3σ limits, respectively, as well as those outside 3σ limits for each statistic considered. These findings are used as an aid to determine the degree of control exercised in producing the lot in question, and to render a final decision as to whether such lot should be accepted, rejected, or inspected in detail.

In addition to the above techniques, sampling inspection plans based on variables may prove to be very helpful. In some instances where the standard deviations for a series of samples indicate control with respect to variability, the criteria may be based only on sample averages. These criteria also may be supplemented by attributes criteria applicable to the sampling results.

Another procedure that uses variables inspection data for a sample includes as the criteria the range as well as the average for each sample selected from a lot. It provides either lot-quality protection or average-quality protection, as prescribed, similar in nature to the sampling plans based on the method of attributes. Another procedure uses the standard deviation for the sample rather than the average range for a set of sub-samples and also incorporates many features of the attributes inspection plans now in operation.

The procedure using the range has not been developed to as great an extent as that employing standard deviation but it is simpler to apply. Early work on this type of criteria was given by Dr. E. P. Coleman in his doctorate dissertation. Work on the criteria using the standard deviation as well as the average is partially completed at the Stanford Research Institute [6] and is similar in nature to the sampling plans incorporated in MIL-STD-105A.

If use is made of all these criteria for acceptance and rejection of individual lots and in addition the data thus accumulated for these samples are plotted on appropriate control charts for the key characteristics for electronic components, the net results should be a quality product at minimum cost. The information that is obtained from such data may be profitably forwarded to engineering and provide a basis for determining whether design changes are necessary on the final product. These results, when supplemented by complaint and field reports should provide a fairly complete system of control for electronic components.

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Where FAULT-FINDING is a *Virtue*

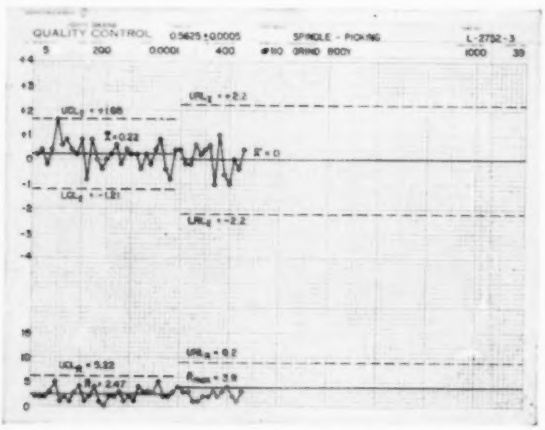
NOW all of us know that fault-finding isn't the recommended short-cut to winning friends and influencing people. Still, there is a place for it—even an honored place—in industry. That's when fault-finding is the by-product of *fact-finding*, basic function of a practical Quality Control program.

We see it work every day at John Deere. Here, dozens upon dozens of "professional fact-finders" are stationed at strategic points throughout John Deere factories, charged—with the help of tens of thousands of instruments and gauges—to probe the vital statistics of manufactured parts, record them, and to expose fault where fault exists.

These men, of course, carry out but one phase—the inspection phase—of the John Deere Quality Control program—a program, incidentally, that embraces the entire scope of manufacturing. Others are just as busily engaged in tabulating these facts and translating them in terms of indicated manufacturing procedure.

The Quality Control program is John Deere's way of making sure that each unit leaving the assembly line stands, trim and efficient—a quality product—ready for the field and ready to serve the cause of better farming.

Here an operator is grinding the body diameter of a cotton picker spindle. The control chart on this machine is similar to thousands of control charts on machines or work stations in the John Deere factories and is designed to assist the operator and supervisor in maintaining tolerances.



This chart is much like the one in the picture at the left and shows how statistical analysis is used to indicate the ability of the process to maintain established tolerances. The projected lines are guide lines used by the operator to aid him in maintaining these tolerances—all part of the John Deere statistical quality control system.

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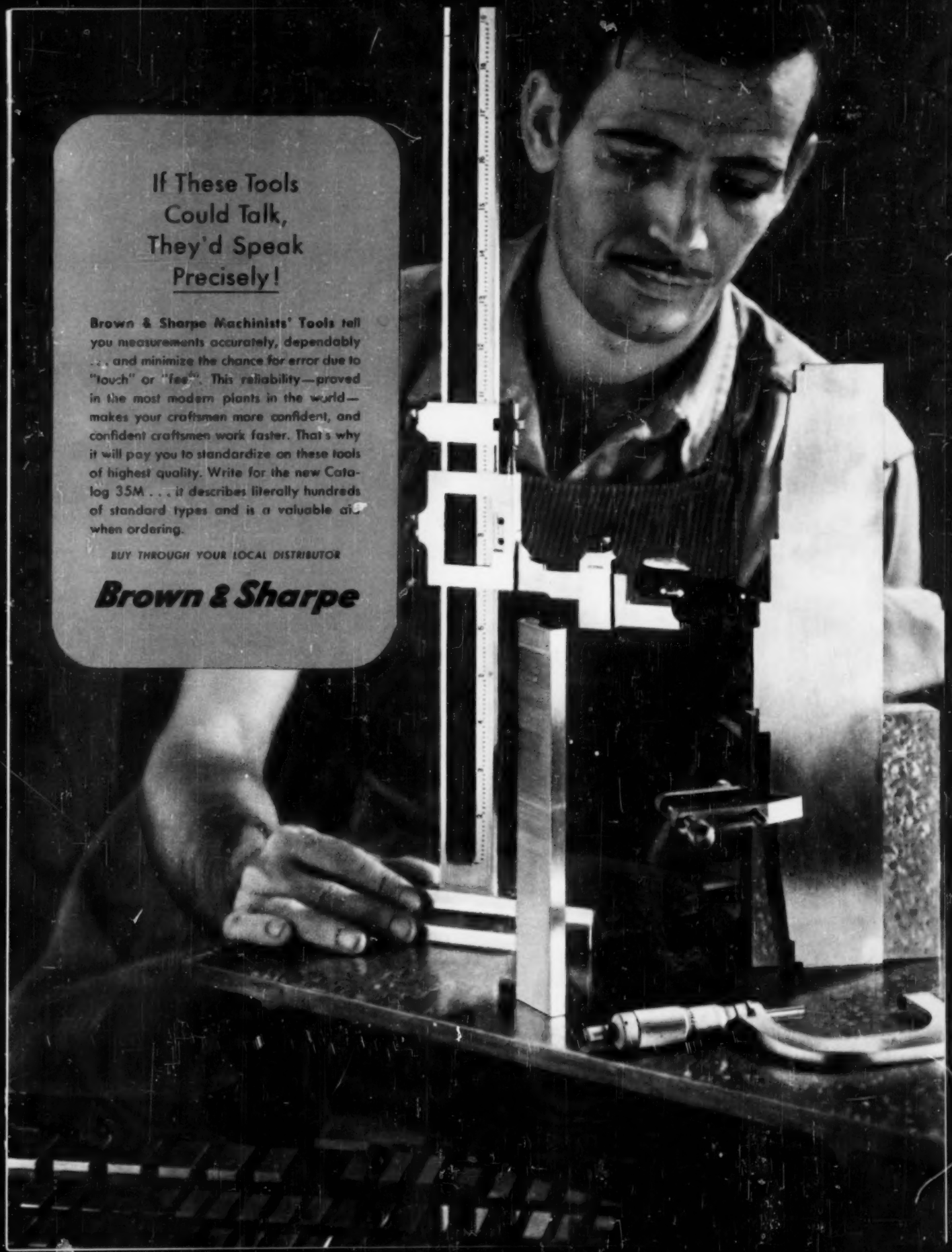
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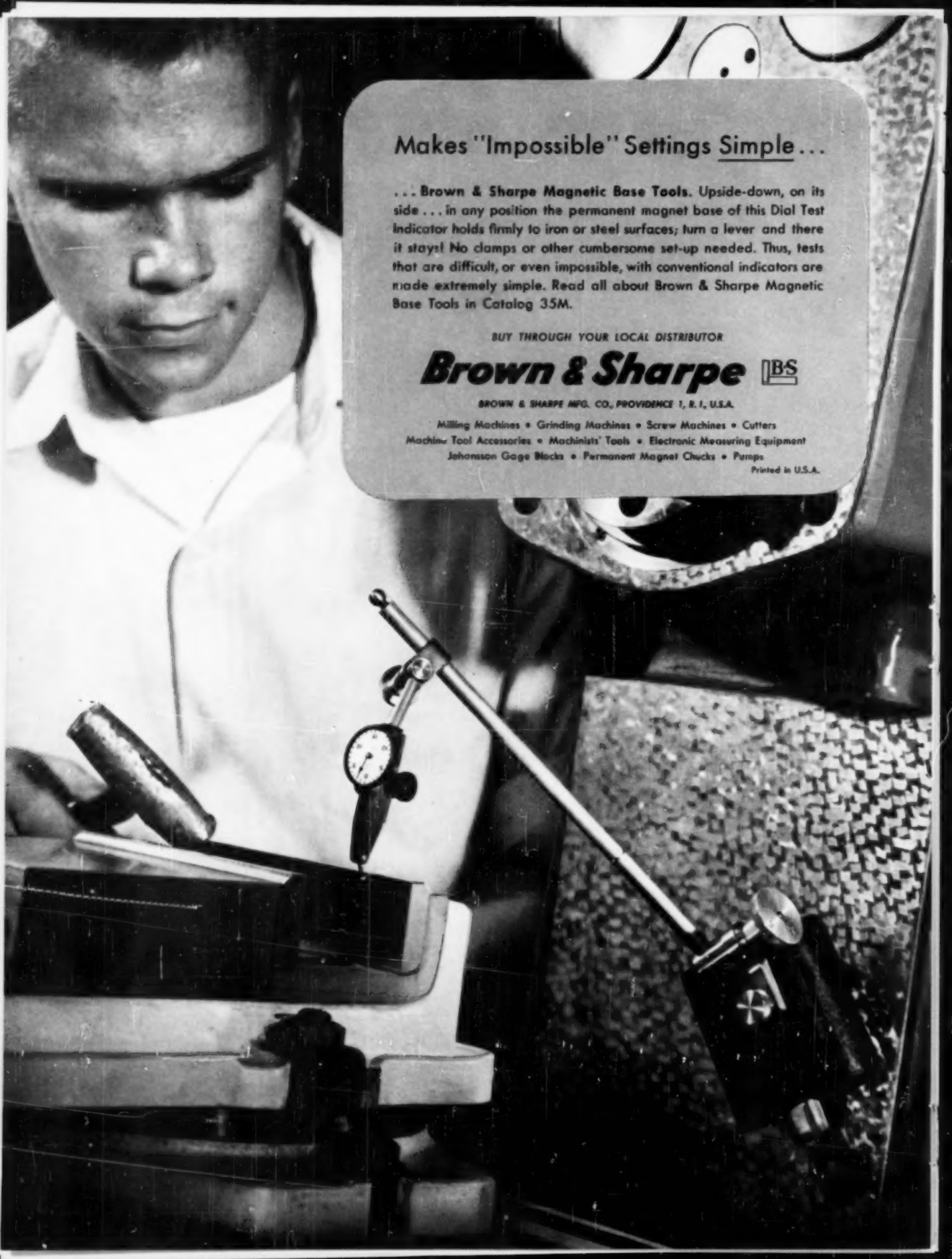
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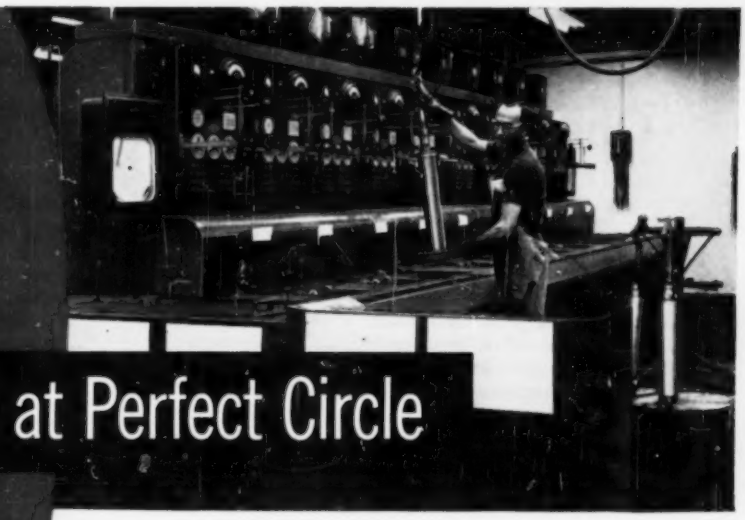


Quality Control at Perfect Circle

Removing rack of rings from plating tank at the completion of its time cycle.

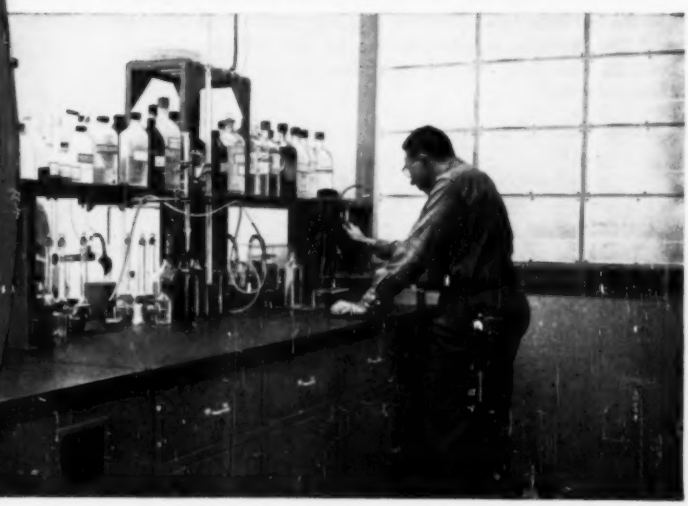
Problems encountered in the chrome plating of piston rings involve chemistry, equipment, processing, people and measurement.

Statistical methods play a continuous role in maintaining control of these factors and assure the highest degree of product conformance and uniformity attainable.

Perfect Circle Corporation, Hagerstown, Indiana. The Perfect Circle Co., Ltd., Toronto, Ontario.

Measuring thickness of chrome plate with Magna-Gage.

Controlling the current density of an electroplating test cell.



Perfect Circle

2 in 1 Chrome Piston Rings

The standard of Comparison

Analysis of Variance When the Numbers of Observations in the Subgroups are Unequal

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On several occasions recently, quality control people have reported that in solving a four-component or higher analysis of variance problem, the interaction sum of squares came out negative. Knowing that a negative sum of squares is mathematically impossible, we have casually pushed the problem aside with the comment, "Oh, you must have made some errors in arithmetic. Go back and re-check your calculations." Upon more careful examination of the problem, however, we find after double checking all of our calculations that a generalization of the usually accepted methods of analysis of variance as outlined in Brownlee[1] or in Griffith, Westman, and Lloyd,[2] may actually lead to an interaction term with a negative sign. Consider the following example from a plant in the Syracuse area.

We have two factors at two levels (e.g. two machines A_1 and A_2 and two operators B_1 and B_2) and wish to make an analysis of variance of the effects of both factors (main effects) and the interaction between the two factors. Let us define a cell as the intersection of a row and a column and the numbers in Table I indicate the sum of observations for each cell. The numbers in parentheses indicate the numbers of observations which were taken to make up this sum.

TABLE I

Factor B at Level	A_1	A_2	Row Total
B_1	11,020 (24)	10,787 (28)	21,807 (52)
B_2	6,163 (12)	5,265 (11)	11,428 (23)
Column Totals	17,183 (36)	16,052 (39)	33,235 (75)

If we now apply a generalization of the usual technique, for example, for the column sum of squares—add the column, square, divide by the number in the column and add for all columns minus a correction term, we find:

Total Sum of Squares (from original data):

$$18{,}268{,}177 - \frac{(33{,}235)^2}{75} = 3{,}540{,}641$$

Column Sum of Squares:

$$\frac{(17{,}183)^2}{36} + \frac{(16{,}052)^2}{39} - \frac{(33{,}235)^2}{75} = 80{,}844$$

Row Sum of Squares:

$$\frac{(21{,}807)^2}{52} + \frac{(11{,}428)^2}{23} - \frac{(33{,}235)^2}{75} = 95{,}790$$

*At the time of writing this article the author was with Syracuse University.

Cell Sum of Squares:

$$\frac{(11{,}020)^2}{24} + \frac{(10{,}787)^2}{28} + \frac{(6{,}163)^2}{12} + \frac{(5{,}265)^2}{11} - \frac{(33{,}235)^2}{75} = 173{,}407$$

The interaction is taken to be the cell sum of squares minus the row and the column sum of squares, or

Interaction Sum of Squares

$$= 173{,}407 - (80{,}844 + 95{,}790)$$

$$= -3{,}227$$

Here the interaction term carries a negative sign even after checking and re-checking our arithmetic. Hence, as such a thing is impossible, there must be some error in the method used to calculate the interaction.

Upon examination of the data which yield this peculiar result, we find that this only occurs when the numbers of observation in the four cells are unequal. In this problem, the numbers were 24, 28, 12, and 11. Checking the literature,[3,4,5,6] we find that some work has been reported on this problem and that to generalize the usual methods to the case of unequal numbers in the cells is not correct. The correct solution to this problem is given by Tsao in his Ph.D. thesis at Minnesota in 1945 and also in part by Snedecor.[6] Tsao develops techniques for solving analysis of variance and covariance problems when the numbers of observations in the cells are not all equal. It is our aim to present here the method which he gives for the case of a two by two analysis (i.e., two factors at two levels) in a form which may be useful to quality control personnel.

In applying these methods we need only to calculate the means of each cell and introduce a quantity P as indicated in Table II.

TABLE II

	A_1	A_2	Difference in Cell Means D	Weights: Ratio of product of no. in cells to sum of no. in cells W	Weighted Difference DW
B_1	11,020 (24) $\bar{X}=459.17$	10,787 (28) $\bar{X}=385.25$	459.17−385.25 = 73.92	$\frac{(24)(28)}{52} = 12.92$	955.05
B_2	6,163 (12) $\bar{X}=513.58$	5,265 (11) $\bar{X}=478.64$	513.58−478.64 = 34.94	$\frac{(11)(12)}{23} = 5.74$	200.56
				$\Sigma W = 18.66$	$\Sigma DW = 1155.61$

$$P = \frac{(\text{Sum of Weighted Differences})^2}{\text{Sum of Weights}} = \frac{(1155.61)^2}{18.66} = 71{,}567$$

The interaction sum of squares is now found by subtracting this quantity P *and* the row sum of squares from the cell sum of squares—thus:

$$\text{Int.} = 173{,}407 - (71{,}567 + 95{,}790) = 6{,}050.$$

Here we see that the sign is positive as it should be. We have used in place of the column sum of squares the quantity P which has been adjusted for the effects of different numbers of observations in the cells.

To test the significance of this interaction, we resort to the original data for the error term which is the total sum of squares minus the cell sum of squares:

$$\text{Error (or Residual)} = 3{,}540{,}641 - 173{,}407 = 3{,}367{,}234$$

Then:

$$F_{1,71} = \frac{\frac{6{,}050}{1}}{\frac{3{,}367{,}234}{71}} < 1.$$

Hence, no significant interaction in this problem. The interaction can then be lumped with the error term in testing the main effects.

Now, not only is the interaction affected by having unequal numbers of observations in the cells, but the main effects are also different. The method used in calculating the main effects depends on the assumptions we are willing to make. One assumption is that the interaction is *not* significant which applies to our problem as we have tested its significance above. In this case, the main effects are:

$$\text{Column Sum of Squares} = P = 71{,}567$$

$$\text{Row Sum of Squares} = \text{Row Sum of Squares (Original)} - \text{Column Sum of Squares (Original)} + P$$

$$= 95{,}790 - 80{,}844 + 71{,}567 = 86{,}513.$$

TABLE III

Source of Variation	d. f.	Sum of Squares	Mean Square	F
Between A's	1	71.567	71.567	1.5
Between B's	1	86.513	86.513	1.8
Error (or Residual)	72	3.373.284	46.850	

None of the effects (A, B or interaction as summarized in Table III) is significant at the 5 percent level. It is noteworthy that the methods of Tsao should always be employed when the numbers of observations in the cells are unequal, and we note that when this proper method is used, no spurious negative interactions appear.

To illustrate these techniques on problems where the interaction is significant, we cite the example in Table IV for easy calculations.

Using the traditional approach:

$$\text{Total S. of Sqs.} = 29 - \frac{(11)^2}{8}$$

$$= 13.875$$

$$\text{Cell S. of Sqs.} = \frac{(5)^2}{2} + \frac{(-1)^2}{1} + \frac{(1)^2}{2} + \frac{(6)^2}{3} - \frac{(11)^2}{8}$$

$$= 10.875$$

TABLE IV*

	A_1	A_2	Row Totals
B_1	2 (4) 3 (9) 5	−1 (1) −1	4 (14)
B_2	1 (1) 0 (0) 1	1 (1) 2 (4) 3 (9) 6	7 (15)
Col. T.	6 (14)	5 (15)	11 (29)

*Numbers in parentheses are squared values.

TABLE V

	A_1	A_2	D	W	DW
B_1	5 (2) X = 2.5	−1 (1) X = −1.0	2.5−(−1.0) = 3.5	$\frac{(2)\ (1)}{3} = \frac{}{2/3}$	2.333
B_2	1 (2) X = 0.5	6 (3) X = 2.0	0.5−2.0 = −1.5	$\frac{(2)\ (3)}{5} = \frac{}{6/5}$	−1.800
				$\Sigma W = \frac{28}{15}$	$\Sigma DW = 0.533$

$$P = \frac{(\Sigma DW)^2}{\Sigma W} = \frac{(0.533)^2}{28/15} = 0.152$$

$$\text{Column S. of Sqs.} = \frac{(6)^2}{4} + \frac{(5)^2}{4} - \frac{(11)^2}{8}$$

$$= 0.125$$

$$\text{Row S. of Sqs.} = \frac{(4)^2}{3} + \frac{(7)^2}{5} - \frac{(11)^2}{8}$$

$$= 0.008$$

Now using the value of P calculated in Table V

$$\text{Interaction} = \text{Cell Sum of Squares} - \text{Row Sum of Squares} - P$$

$$= 10.875 - 0.008 - 0.152 = 10.715$$

$$\text{Error Sum of Squares} = \text{Total Sum of Squares} - \text{Cell Sum of Squares}$$

$$= 13.875 - 10.875 = 3.000$$

$$F_{1,5} = \frac{\frac{10.715}{1}}{\frac{3.000}{5}} = \frac{10.715}{0.6} = 17.86$$

which is significant at the one percent level.

Hence assuming a significant interaction; i.e. the interaction is not zero in the parent population, we proceed to test the main effects. But now the main effects are different and they depend on further assumptions concerning the data. There are two assumptions:

(1) That the sample we have has the same stratification in its cells as the parent population. Called: Restriction of "weighted means." The main effects are:

(Continued on page 56)

View at left is a reproduction of an x-ray photograph of a section of a semi-pneumatic tire. Note the defect which occurred at the splice (where the open ends of the tire are joined together by vulcanization). This tire was rejected. Only tires with a perfect splice are passed for shipment.

A conveyor belt carries the tires into the fluoroscope equipment for inspection by x-rays for soundness of splice.

Fluoroscopic detection
used for Tire Inspection

Soundness of splice is a vital factor of quality control in the manufacture of two distinct lines of semi-pneumatic tires by The Ohio Rubber Company. One line known under the trade name "AIR KINGS" is designed for a wide diversity of INDUSTRIAL applications. The other line known as "SOIL KINGS" have various applications on such heavy farm machinery as plows, planters, cultivators and other types of agricultural equipment.

Special fluoroscopic equipment designed and built by The Ohio Rubber Company is employed in the inspection of every "AIR KING" INDUSTRIAL tire and every "SOIL KING" agricultural tire. Only those tires which pass the fluoroscopic test for soundness of splice are approved for shipment to customers. Inspection by fluoroscope is the only positive method of determining the vital quality factor of soundness of splice.

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Column Sum of Squares = Weighted square of the difference in the two column means, where weight is product of number in each column divided by the sum of the numbers in the two columns.

Row Sum of Squares = Weighted square of difference in row means. (Same type of weight.) This gives the same results as in the traditional method above.

(2) That the sample we have came from a population with equal frequencies in cells. Called: Restriction of the "unweighted means." The main effects are:

Column Sum of Squares = Square of the sum of differences in cell means divided by the sum of the reciprocals of the cell weights.

Row Sum of Squares = Square of the sum of differences in cell means in first and second columns divided by the sum of the reciprocals of the respective cell weights.

Applying each of these restrictions to our problem, (Tables IV and V), we find:

(1) Restriction of "weighted means:"

$$\text{Col. S. S.} = \frac{(4)(4)}{8}\left[\frac{6}{4} - \frac{5}{4}\right]^2$$

$$= 0.125$$

$$\text{Row S. S.} = \frac{(3)(5)}{8}\left[\frac{4}{3} - \frac{7}{5}\right]^2$$

$$= 0.008$$

(2) Restriction of "unweighted means:"

$$\text{Col. S. S.} = \frac{([2.5 - (-1.0)] + [0.5 - (2.0)])^2}{\frac{3}{(2)(1)} + \frac{5}{(2)(3)}}$$

$$= 1.714$$

$$\text{Row S. S.} = \frac{([2.5 - .5] + [-1 - 2.0])^2}{\frac{4}{(2)(2)} + \frac{4}{(3)(1)}}$$

$$= 0.429$$

These results are summarized for the "weighted mean" restriction in Table VI; for the "unweighted mean" restriction in Table VII. In each case neither A nor B effect is significant at the five percent level.

TABLE VI

Source of Variation	d. f.	Sum of Squares	Mean Square	F
Between A's	1	0.125	0.125	<1
Between B's	1	0.008	0.008	<1
A×B Interaction	1	10.715	10.715	17.86
Error	5	3.000	0.600	

TABLE VII

Source of Variation	d. f.	Sum of Squares	Mean Square	F
Between A's	1	1.714	1.714	2.86
Between B's	1	0.429	0.429	<1
A×B Interaction	1	10.715	10.715	17.86
Error	5	3.000	0.600	

Note: It may be troublesome to some that the total sum of squares is not the same for Tables VI and VII (being 13.848 and 15.860, respectively). However, Snedecor,[60] says "when through accident, or under the limitations of an experimental technique, erratic losses in data occur, the addition theorem for sums of squares is annulled and the analysis of variance must be modified."

Now, to some quality control people, it may appear quite laborious to apply this new technique in case the numbers of observations in the cells are unequal. This technique becomes even more complicated when extended to the case of a two by q table (one factor at two levels, another at q levels) and for a p by q table. (The more general case is treated by Tsao[63] and in part by Snedecor.[60])

One might justifiably ask, "Isn't there some easier way?" Fortunately the answer is "yes" if you are willing to restrict the data somewhat. It can be shown that if the numbers of observations in the cells are proportional (this includes the case of equal numbers, of course), the general methods of variance analysis can be applied. So, if we do not have proportional numbers in the cells, either some data may be deleted at random or more observations may be taken in order to achieve this proportionality.

Looking again at the problem in Table IV, the numbers now are in the ratio 2:1 and 2:3 (Row 1 and Row 2). If only the number in the lower right hand cell were one, these cell numbers would be proportional 2:1; 2:1 across the rows or 2:2; 1:1 down the columns). Since in this case we can't get more data, let us select one of the three observations in the last cell at random as representative of that cell. We might put the three numbers in a hat (1, 2, and 3) and select one at random. Or, we might consult a table of random numbers. If we should select the number two to retain, we would have the data shown in Table VIII.

TABLE VIII

	A_1		A_2		
B_1	2 3 5	(4) (9)	-1 -1	(1)	4 (14)
B_2	1 0 1	(1) (0)	2 2	(4)	3 (5)
	6	(14)	1	(5)	7 (19)

Applying the general methods:

$$\text{Total S. of Sqs.} = 19 - \frac{(7)^2}{6}$$

$$= 10.833$$

$$\text{Cell S. of Sqs.} = \frac{(5)^2}{2} + \frac{(1)^2}{2} + \frac{(-1)^2}{1} + \frac{(2)^2}{1} - \frac{(7)^2}{6}$$

$$= 9.833$$

(Continued on page 60)

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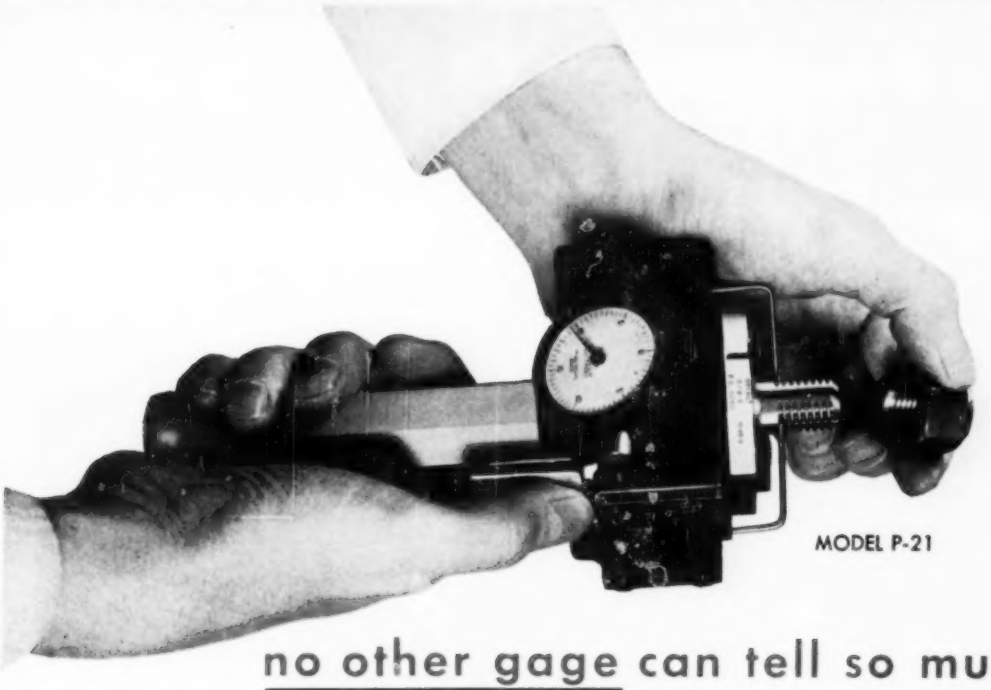

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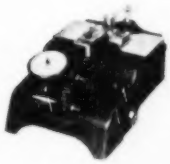

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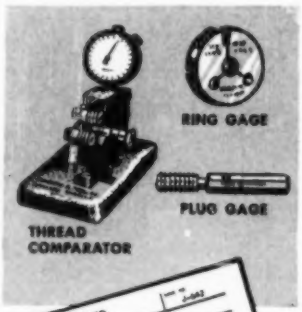

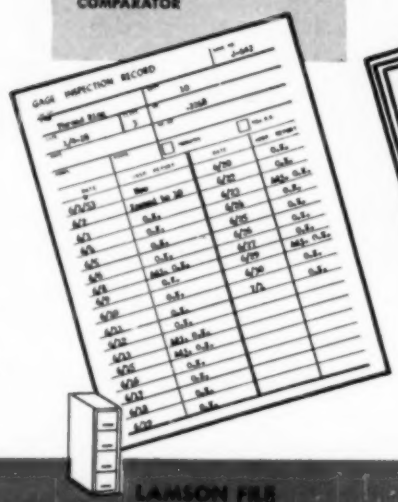

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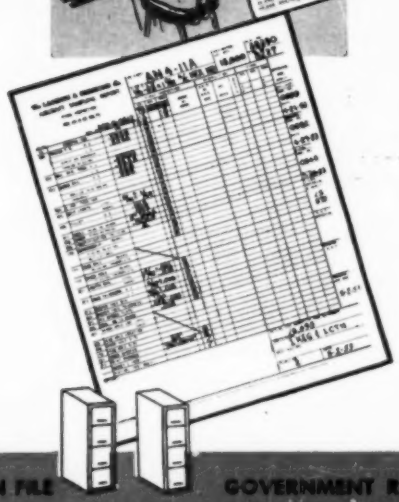

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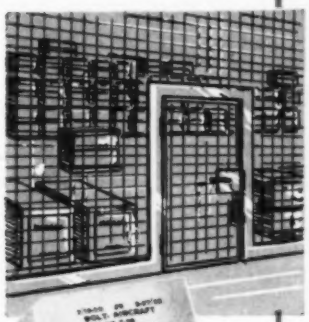

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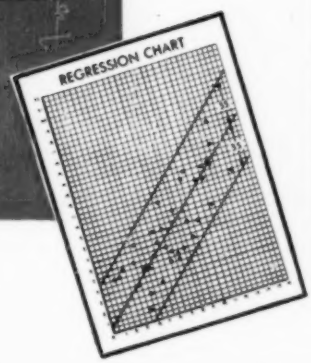

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$$\text{Column S. of Sqs.} = \frac{(6)^2}{4} + \frac{(1)^2}{2} - \frac{(7)^2}{6}$$

$$= 1.333$$

$$\text{Row S. of Sqs.} = \frac{(4)^2}{3} + \frac{(3)^2}{3} - \frac{(7)^2}{6}$$

$$= 0.166$$

The results now are as shown in Table IX. Here even the interaction is not significant at the five percent level. (We know it is significant, however, but restricting our data fails to show its significance. This effect would not be so serious on a larger volume of data).

TABLE IX

Source of Variation	d. f.	Sum of Squares	Mean Square	F
Between A's	1	1.333	1.333	2.67
Between B's	1	0.166	0.166	<1
A × B Interaction	1	8.334	8.334	16.67
Error	2	1.000	0.500	
Totals	5	10.833		

If the reader will now take the trouble to apply the methods of this article to this problem of proportionate cells, he will arrive at the same results as in Table IX regardless of the restriction he assumes.

In conclusion, a few observations are in order:

1) A negative interaction is impossible if the proper method is applied
2) Generalizing the equal cell technique to problems of unequal cells is not valid
3) If one has experimental data with unequal numbers in the cells, the technique of Tsao must be applied — whether the interaction by the general method is negative *or not*. The proper technique will depend on the assumptions one is willing to make.
4) If the numbers of observations in the cells are proportional, the equal-cell methods apply. Usually the most practical method of approach is to fit the experiment to an equal or proportional cell model either by deleting readings at random or, whenever possible, by taking more readings.

Appendix

For the sake of simplification for some, the following mathematical formulas are presented to generalize these techniques for the case of a two by two table.

Let T_{ij} be the sum of all observations in the cell located at the intersection of column i and row j. Let n_{ij} be the number of observations in this cell and $\overline{X}_{ij}$ the mean of this cell. A dot will be used to indicate the average when i (or j) takes on the values one and two. Such a two by two table is shown in Table X.

Then the quantity P is given by:

$$P = \frac{\left[\sum_i \frac{n_{1i}\, n_{2i}}{n_{\cdot i}} (\overline{X}_{1i} - \overline{X}_{2i})\right]^2}{\sum_i \frac{n_{1i}\, n_{2i}}{n_{\cdot i}}}$$

TABLE X

	A_1	A_2	Row Totals
B_1	T_{11} n_{11} $\overline{X}_{11}$	T_{21} n_{21} $\overline{X}_{21}$	$T_{\cdot 1}$ $n_{\cdot 1}$ $\overline{X}_{\cdot 1}$
B_2	T_{12} n_{12} $\overline{X}_{12}$	T_{22} n_{22} $\overline{X}_{22}$	$T_{\cdot 2}$ $n_{\cdot 2}$ $\overline{X}_{\cdot 2}$
Column Totals	$T_{1\cdot}$ $n_{1\cdot}$ $\overline{X}_{1\cdot}$	$T_{2\cdot}$ $n_{2\cdot}$ $\overline{X}_{2\cdot}$	$T_{\cdot\cdot}$ $n_{\cdot\cdot}$ $\overline{X}_{\cdot\cdot}$

which for two rows and two columns reduces to:

$$P = \frac{\left[\frac{n_{11}\, n_{21}}{n_{\cdot 1}} (\overline{X}_{11} - \overline{X}_{21}) + \frac{n_{12}\, n_{22}}{n_{\cdot 2}} (\overline{X}_{12} - \overline{X}_{22})\right]^2}{\frac{n_{11}\, n_{21}}{n_{\cdot 1}} + \frac{n_{12}\, n_{22}}{n_{\cdot 2}}}$$

If now we adopt the Q notation for the general analysis of variance methods (see Griffith, Westman, and Lloyd[2]), then

Q_1 = Total Sum of Squares of all observations

$$Q_2 = \frac{T_{11}^2}{n_{11}} + \frac{T_{12}^2}{n_{12}} + \frac{T_{21}^2}{n_{21}} + \frac{T_{22}^2}{n_{22}} \quad \text{(Cells)}$$

$$Q_3 = \frac{T_{1\cdot}^2}{n_{1\cdot}} + \frac{T_{2\cdot}^2}{n_{2\cdot}} \quad \text{(Columns)}$$

$$Q_4 = \frac{T_{\cdot 1}^2}{n_{\cdot 1}} + \frac{T_{\cdot 2}^2}{n_{\cdot 2}} \quad \text{(Rows)}$$

$$Q_5 = \frac{T_{\cdot\cdot}^2}{n_{\cdot\cdot}} \quad \text{(Correction Term)}$$

We can summarize these techniques as follows:

Regardless of the assumptions made:

$$\text{Total S. S.} = Q_1 - Q_5$$

$$\text{Error S. S.} = Q_1 - Q_2$$

$$\text{Interaction S. S.} = Q_2 - Q_4 - P$$

And for the main effects assuming:

A. Non-significant interaction.

$$\text{Column S. S.} = P$$

$$\text{Row S. S.} = Q_4 - Q_5 + P$$

B. Significant interaction and restriction of:

1) "weighted means"

$$\text{Column S. S.} = \frac{n_{1\cdot}\, n_{2\cdot}}{n_{\cdot\cdot}} (\overline{X}_{1\cdot} - \overline{X}_{2\cdot})^2$$

$$= Q_3 - Q_5$$

$$\text{Row S. S.} = \frac{n_{\cdot 1}\, n_{\cdot 2}}{n_{\cdot\cdot}} (\overline{X}_{\cdot 1} - \overline{X}_{\cdot 2})^2$$

$$= Q_4 - Q_5$$

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2) "unweighted means"

$$\text{Column S. S.} = \frac{[(\bar{X}_{11} - \bar{X}_{21}) + (\bar{X}_{12} - \bar{X}_{22})]^2}{\frac{n_{\cdot 1}}{n_{11}\, n_{21}} + \frac{n_{\cdot 2}}{n_{12}\, n_{22}}}$$

$$\text{Row S. S.} = \frac{(\bar{X}_{11} - \bar{X}_{12}) + (\bar{X}_{21} - \bar{X}_{22})]^2}{\frac{n_{1\cdot}}{n_{11}\, n_{12}} + \frac{n_{2\cdot}}{n_{21}\, n_{22}}}$$

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Probability Limits for the Average Chart When Process Standards Are Unspecified

E. P. KING

National Bureau of Standards and Eli Lilly and Company

INTRODUCTION

There are two distinct but related phases of control chart practice—phase I which is termed "Control with No Standard Given" and phase II "Control with Respect to a Given Standard." The purpose in phase I is to discover whether measurements from samples vary among themselves by an amount greater than should be attributed to chance. The purpose in phase II is to discover whether measurements depart significantly from "standard values" which may have been established by experience based on prior data, by economic considerations, or by reference to the desired state of the process as designated by the specifications. The material in this paper will be concerned with phase I only.

The customary procedure in phase I is to classify the total number, N say, of measurements to be drawn from the process into m subgroups of size n each according to some rational method of subgrouping. For each subgroup (or sample) a mean $\bar{X}$ and a range R are calculated and their values plotted on separate charts in the order drawn. Using prescribed formulas based on the data collected and the sample size, upper and lower control limits are computed for each chart. (In the case of the average chart, these limits are computed as $\bar{\bar{X}} \pm A_2\bar{R}$ where $\bar{\bar{X}}$ is the grand average of all the observations, $\bar{R}$ is the average range, and A_2 is a factor whose values are tabulated as a function of n). If all the points on both charts fall within control limits, the hypothesis that the process is in statistical control is accepted. Otherwise it is rejected.

The above procedure may be regarded as a decision rule used to determine whether or not a process is in a state of statistical control. Like all other decision rules, if it is used frequently enough it will occasionally make mistakes, i.e., wrong decisions. These mistakes will be of two types. In the first place the decision rule may conclude that the process is out of control when, in fact, it is in control. This wrong decision, or type I error as it is sometimes called, is made whenever chance causes alone result in one or more $\bar{X}$ or R values falling outside the control limits. In the second place the rule may decide that the process is in control when actually it is not. This type II error occurs whenever assignable causes are present but not "strong enough" to force points outside the control band on either the $\bar{X}$ or the R chart.

This article is concerned only with the $\bar{X}$ chart. Its purpose is to present a slightly different method of computing control limits which should give the quality control engineer better control over the frequency of occurrence of wrong decisions.

DISADVANTAGE OF THE STANDARD METHOD

To effectively control the two types of errors discussed above, the control band on the $\bar{X}$ chart must serve two conflicting purposes: (1) it must be wide enough to insure that points will rarely fall outside the limits due to chance alone, and (2) it must be narrow enough to insure that sudden shifts in level of appreciable magnitude will result in one or more points falling outside the limits, thus indicating the presence of an assignable cause.

When the $\bar{X}$ chart is constructed by the standard method, its ability to meet these two demands depends rather strongly on the number of measurements used. One combination that has demonstrated its effectiveness in practical applications is Shewhart's plan of using 25

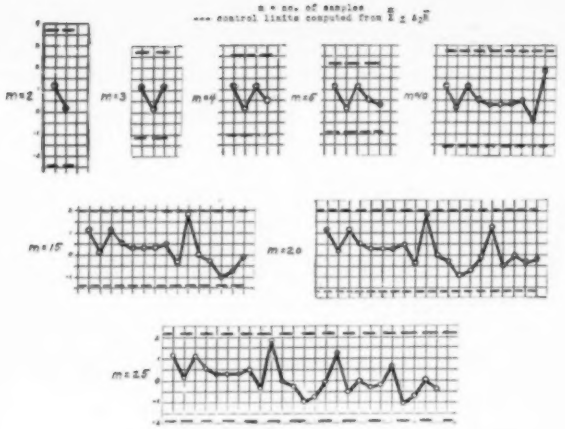

Figure 1

samples of five measurements each. Under the special assumption of normality, the probability of a type I error for this plan has been computed to be about 0.05. That is, when the process is in statistical control, in about one chart out of twenty at least one $\overline{X}$ among the 25 averages calculated from 25 samples of five will fall outside the control limits $\overline{\overline{X}} \pm A_2 \overline{R}$. Thus the control band in this case is wide enough to provide good protection against type I errors. In addition, there is adequate practical evidence and some theoretical evidence that this plan has considerable ability to detect sudden shifts in the process level. (The control band is narrow enough to provide good protection against type II errors.)

However, this picture changes considerably when the average chart is based on a smaller amount of data. As the number of subgroups, m, decreases (for n fixed) the probability of a type I error decreases. In fact, when the chart is based on only two samples (m=2), there is substantially no chance of a type I error. This "over-protection" against the chance occurrence of points beyond control limits is obtained at the expense of a considerable loss in "detecting ability" or power. The control band is so wide that it includes the normal variation of sample means from a controlled process and still has "room to burn." Because of this excess width, only a violent shift in the process level could result in an out-of-control $\overline{X}$ value.

Some practical evidence of this fact is shown in Fig. 1. Observations were drawn from a table of random normal deviates to represent measurements on a statistically controlled process. These observations were divided into subgroups of two and an average $\overline{X}$ and a range R calculated for each subgroup. The first chart is an $\overline{X}$ chart based on the first two $\overline{X}$ values (with limits set at $\overline{\overline{X}} \pm A_2 \overline{R}$ where $\overline{\overline{X}}$ and $\overline{R}$ are computed from the first two samples only). Each additional chart is formed by adding one or more $\overline{X}$ values (in the order drawn) to the preceding chart and recomputing the control limits. Note that the limits for the first few charts are very far apart, while those for the charts based on 20 and 25 samples give a more realistic picture of normal variation. Putting it another way, the chart based on a few subgroups seldom gives a "false alarm" but this assurance is obtained at a high price. The chart frequently fails to sound an "alarm" when there is a "fire."

PROPOSED METHOD

The penalty for using a very small number of subgroups can be reduced somewhat by using a different multiplier for $\overline{R}$ in the expression $\overline{\overline{X}} \pm A_2 \overline{R}$. This multiplier can be chosen in such a way that the probability of a type I error is approximately 0.05 regardless of the number of subgroups used. Specifically, the factor A_2, which depends only on the sample size n, can be replaced by a new factor, C say, which depends both on the sample size, n, and on the number of samples, m. A set of values for C is provided graphically in Fig. 2. If control limits are placed at $\overline{\overline{X}} \pm C\overline{R}$, and if the process is normal with fixed mean and standard deviation, then one or more points will fall outside the control band only on about one chart out of every 20 constructed, regardless of the number of samples used. Although the change from "A_2" values to "C" values results in a much narrower control band when the number of subgroups is small, it should be noted that "C" approaches "A_2" rather rapidly as m increases. In fact, in the particular case of 25 subgroups, A_2 and C are obviously identical and the proposed control limits take the familiar form $\overline{\overline{X}} \pm A_2 \overline{R}$.

EXAMPLE

Suppose four samples of two measurements each are taken at one hour intervals from a process and the following calculations made

$\overline{X}$	R		
1.17	0.05		
0.14	1.64	$\overline{\overline{X}} = 0.745$	$\overline{R} = 0.96$
1.13	1.40		
0.54	0.76		

The standard limits would be computed as $\overline{\overline{X}} - A_2 \overline{R} = -1.06$ and $\overline{\overline{X}} + A_2 \overline{R} = 2.55$. With the proposed method, one would enter Fig. 2 on the curve n = 2 and read the value C = 1.36 corresponding to m = 4. The limits computed by the proposed method would be $\overline{\overline{X}} - C\overline{R} = -0.56$ and $\overline{\overline{X}} + C\overline{R} = 2.05$.

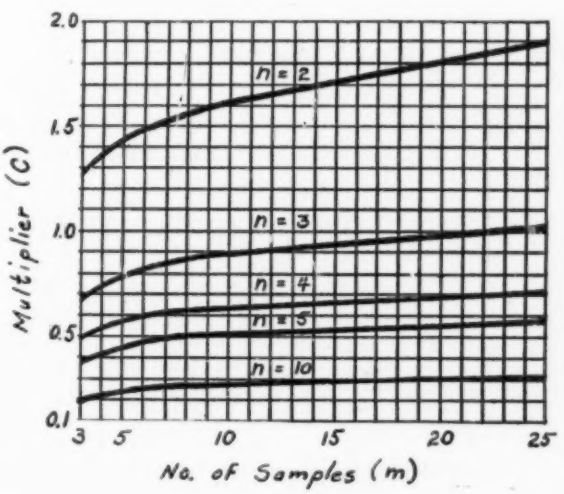

Figure 2—Values of C

FURTHER CONSIDERATIONS

Two factors should be emphasized as precautions in the use of the procedure described in this paper. First, although the use of the C factor gives "short run" charts a "better break", this does not alter the fact that charts based on about 25 subgroups have much more power than those based on three or four subgroups. Second, the C factors are approximations. One approximation was made by ignoring the sampling fluctuations of $\overline{R}$ in calculating the probability of a type I error. Another, more serious approximation was made by obtaining many of the C values from random sampling experiments.

Appendix

The factor A_2 is defined[1] as $A_2 = 3/(\sqrt{n}\, d_2)$, where d_2 is the expected value of the range of a sample of size n in repeated sampling from a normal distribution with unit variance. In this article, the number "3" in the expression for A_2 is replaced by a factor, k_m, which depends on the number of subgroups. This factor is chosen in such a way that when the distribution of the process is normal with mean μ and variance σ^2 the probability is approximately 0.95 that all the $\overline{X}$ values will fall within a disatnce $k_m\sigma/\sqrt{n}$ from their grand average, $\overline{\overline{X}}$. That is

$$\text{Prob}\left\{ |\overline{X}_1 - \overline{\overline{X}}| \leq k_m\, \sigma/\sqrt{n}, \ldots\ldots, |\overline{X}_m - \overline{\overline{X}}| \leq k_m\, \sigma/\sqrt{n} \right\} \cong 0.95 \qquad (1)$$

where $\overline{X}_1, \overline{X}_2, \ldots, \overline{X}_m$ are the means of the m successive samples of size n, and $\overline{\overline{X}} = (X_1 + \ldots + X_m)/m$. The values of k_3 and k_4 are obtained from theoretical considerations (see reference 3). For $m > 4$ the values of k_m are obtained by constructing the sampling distribution of $\dfrac{\max |\overline{X}_i - \overline{\overline{X}}|}{\sigma/\sqrt{n}}$ for each m from a table of random normal deviates.[2] The 95 percentile of this sampling distribution is used as the estimate of k_m, because expression (1) is equivalent to

$$\text{Prob}\left\{ \frac{\max |\overline{X}_i - \overline{\overline{X}}|}{(\sigma/\sqrt{n})} \leq k_m \right\} \cong 0.95$$

The values of C are then taken as $C = k_m/(\sqrt{n}\, d_2)$.

References

1. *ASTM Manual on Quality Control of Materials*, Part 3—Control Chart Method of Analysis and Presentation of Data, American Society for Testing Materials, 1951.
2. H. Wold, *Random Normal Deviates*, Tracts for Computers, No. XXV, Cambridge University Press, 1948.
3. E. P. King, "The Operating Characteristic of the Control Chart for Sample Means," *Annals of Mathematical Statistics*, Vol 23, No. 3 (1952) pp.384-95.

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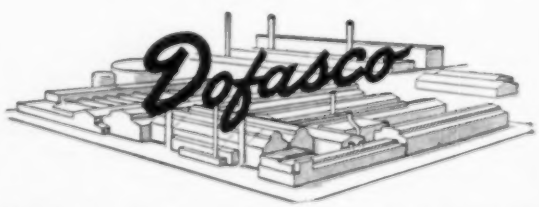

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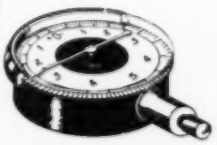

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WHEREAS, the ever increasing standard of living which Americans enjoy and our ability as a nation to defend ourselves successfully in time of war are due largely to our ability to out-produce all other nations of the world; and

WHEREAS, the basic technique of quality control, although developed before World War II, was not widely used until the war, and during the war aided in enabling us to produce military goods of quality and quantity which exceeded the most optimistic estimates; and

WHEREAS, The American Society for Quality Control, and organization of approximately 8,500 Quality Control Engineers, is dedicated to the purpose of furthering the use of quality control by statistical means; and

WHEREAS, through the techniques of statistical quality control more and better consumer goods are made available to the American public at lower cost; and

WHEREAS, The American Society for Quality Control will hold its Eighth Annual Convention in St. Louis on June 9, 10 and 11, 1954; and

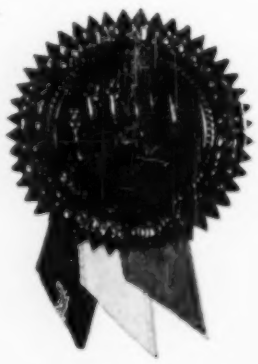
WHEREAS, it is our desire to welcome the delegates and their families to St. Louis and to wish them a most enjoyable stay in our city:

NOW, THEREFORE, I, Raymond R. Tucker, Mayor of the City of St. Louis, do hereby proclaim the week beginning June 6, 1954, as

"STATISTICAL QUALITY CONTROL WEEK"

in the City of St. Louis.

IN WITNESS WHEREOF, I have hereunto set my hand and caused to be affixed the Seal of the City of St. Louis on this seventh day of April, A.D., 1954.



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8th annual

AMERICAN SOCIETY FOR QUALITY CONTROL

Kiel Auditorium, St. Louis, Missouri

SCHEDULE OF EVENTS

TUESDAY, JUNE 8, 1954

3:30 p. m. Pre-Convention Social — Anheuser-Busch

WEDNESDAY, JUNE 9, 1954

8:30 a. m. Registration — Kiel Auditorium
8:30 a. m. to 5:30 p. m Exhibits open — Kiel Auditorium
11:00 a m. Opening Assembly — Opera House, Kiel Auditorium
Speaker: Mr. E. T. T. Williams, President of
The Lambert Company, Jersey City, New Jersey
12:15 p. m. Luncheon — Kiel Auditorium
2:30 to 5:10 p. m. Technical Sessions — Kiel Auditorium
4:00 p. m. Annual Meeting — American Society for Quality Control, Kiel Auditorium
9:00 p. m. Social Evening — Gold Room, Jefferson Hotel

THURSDAY, JUNE 10, 1954

8:30 a. m. Registration — Kiel Auditorium
8:30 a. m. to 5:30 p. m. Exhibits open — Kiel Auditorium
9:00 to 11:40 a. m. Technical Sessions — Kiel Auditorium
12:15 p. m. Luncheon — Kiel Auditorium
Speaker: Mr. W. H. Martin, Deputy Assistant
Secretary of Defense, Washington, D.C.
2:30 to 5:10 p. m. Technical Sessions — Kiel Auditorium
6:15 p. m. Annual Banquet — Gold Room, Jefferson Hotel

FRIDAY, JUNE 11, 1954

8:30 a. m. Registration — Kiel Auditorium
8:30 a. m. to 5:30 p. m. Exhibits open — Kiel Auditorium
9:00 to 11:40 a . m. Technical Sessions — Kiel Auditorium
12:15 p. m. Luncheon — Kiel Auditorium
Speaker: Mr. G. A. Rohlfing, Personnel Director
Aluminum Company of America, Bauxite, Arkansas
2:30 to 3:40 p. m. Technical Sessions — Kiel Auditorium
6:00 p. m. Convention closes

LADIES' PROGRAM

TUESDAY, JUNE 8, 1954

3:30 p. m. Anheuser-Busch Pre-Convention Social

WEDNESDAY, JUNE 9, 1954

8:30 to 9:45 a. m. Kaffee Klatsch, Crystal Room, Jefferson Hotel
10:00 a. m. to 1:00 p. m. Guided Tour of City, including the famed Chimpanzee Show
1:00 to 2:30 p. m. Luncheon, Missouri Athletic Club
9:00 p. m. Social Evening, Gold Room, Jefferson Hotel

THURSDAY, JUNE 10, 1954

9:30 to 10:30 a. m. Coffee Hour and Fashion Show, Scruggs-Vandervoort-Barney, Tea Room
4:30 to 6:00 p. m. Social Hour, Jefferson Hotel
8:30 p. m. Tickets available for evening activities:
Municipal Opera, Show Boat (Melodrama 'Ole Time)
Admiral Boat Trip

FRIDAY, JUNE 11, 1954

9:30 to 10:30 a. m. Kaffee Klatsch, Crystal Room, Jefferson Hotel, "Sunny California"
8:30 p. m. Tickets available for evening activities:
Municipal Opera, Show Boat (Melodrama 'Ole Time)
Admiral Boat Trip

POINTS OF INTEREST

Convention Headquarters — Jefferson Hotel

Luncheons — Kiel Auditorium

Ladies' Headquarters — East Room, Jefferson Hotel

Refreshments — Courtesy of Coca Cola, Inc.

Information Booths — Jefferson Hotel, Kiel Auditorium

convention

CONVENTION HIGHLIGHTS

COPY OF TRANSACTIONS . . . A handsome book for your library — with illustrations and copies of all speeches. It will serve as a handy reference to a wealth of valuable information. They will be available for ticket holders as indicated on the registration form. Additional copies will be available at the convention for $3.00 each. Copies may also be obtained by mail for $3.50 each from the American Society for Quality Control, Inc., 70 East 45th St., New York 17, N. Y.

BOOK BOOTH . . . Books on all phases of Quality Control and many related subjects will be on sale . . . in a spacious lounge with plenty of easy chairs. You can browse and relax in comfort. Several authors are scheduled to be on hand for autographs and discussion of their books.

SOCIAL EVENING . . . We know what's going to happen — but we aren't talking. A hint is all you get: The activities will be typical of those you would find at some of the world's famous vacation spots. One thing for sure — there'll be plenty of fun for everyone. That's all for now! Just be sure to come.

PLANT TOURS . . . Trips that will be both interesting and educational . . . through plants which are representative of the highly diversified industry in St. Louis. All tours start at 2:00 p.m. from Kiel Auditorium.

Wednesday: Anheuser-Busch, Falstaff Breweries, and Century Electric (Motors). Thursday: Chevrolet, Continental Can, Century Electric, and Elder Manufacturing (Shirts) . . . Anheuser-Busch and Falstaff Breweries. Friday: Magic Chef, Carter Carburetor, Chevrolet, Elder Manufacturing, and Century Electric.

Only a limited number can be accommodated on each tour. Obtain your tickets early — at the Plant-Transportation Booth in the Registration Area. Tickets for transportation for Thursday and Friday tours must be purchased 24 hours in advance.

EXHIBITS . . . We have space for the largest number of exhibitors in the history of our convention . . . and most of it will be filled. There will be many gage and inspection equipment manufacturers with booths . . . and many companies with exhibits on how Quality Control works in their particular industry. An opportunity for you to pick up many new ideas.

TECHNICAL PROGRAM . . . Well-known speakers from all over the nation . . . representing the widest variety of industries you could imagine. They will tell you of their techniques . . . and how they have solved problems of Quality Control. You will find their experience and knowledge of great value.

TECHNICAL SESSIONS

SERIES	A	B	C	D
PERIOD 1	Theme: **General Interest.** Moderator: H. J. BECKER, American Steel & Wire Co., Waukegan, Ill. Speaker: WAYNE M. BIKLEN, Quality Control Manager, American Safety Razor Corp., Brooklyn 1, N. Y. Subject: CAN INCENTIVES AND QUALITY LIVE TOGETHER? Speaker: SOLOMON BARKIN, Director of Research, Textile Workers Union of America, (CIO), 99 University Place, New York 3, N. Y. Subject: UNION INTEREST IN QUALITY CONTROL.	Theme: **Armed Services.** Moderator: ROBERT M. HOFSTEAD, Bristol Laboratories, Inc., P. O. Box 657, Syracuse, N. Y. Speaker: LT. COL. RALPH M. LOCKHART, Office of Ass't Secretary of Defense, (Supply & Logistics), Washington 25, D. C. Subject: THE DEPARTMENT OF DEFENSE INSPECTION PROGRAM. Speaker: ROBERT L. STORER, Chief, Quality Control Branch, Ordnance Ammunition Center, U.S. Army, Joliet, Ill. Subject: THE USE OF CONTINUOUS SAMPLING IN AMMUNITION PROCUREMENT.	Theme: **Aircraft.** Moderator: C. A. COVINGTON, Manager of Quality Control, Convair, San Diego 12, Calif. Speaker: W. C. HITT, Ass't. Chief of Quality Control, Douglas Aircraft, Sta Monica, Calif. Subject: NON-DESTRUCTIVE TESTING AND INSPECTION. Moderator: W. L. HUMPHREY, Quality Manager, Bell Aircraft Corp., Fort Worth, Texas. Speaker: DAVID A. HILL, Director of Quality Control, Hughes Aircraft, Culver City, Calif. Subject: IMPROVING VENDOR QUALITY PERFORMANCE.	Theme: **Business Operations.** Moderator: CHARLES A. BICKING, Office of Chief of Ordnance, Washington 25, D. C. Speaker: WINSTON C. DALLECK, Quality Control Program Director, United Air Lines, Inc., 5959 South Cicero Avenue, Chicago, Ill. Subject: STATISTICAL QUALITY CONTROL AT WORK IN AIRLINE ACCOUNTING. Moderator: HOWARD L. JONES, Illinois Bell Telephone Company, Chicago, Ill. Speaker: ROBERT B. SELOVER, Director of Personnel Research, The Prudential Insurance Company of America, Newark, N. J. Subject: SQC IN OFFICE PROCEDURES AND CLERICAL WORK.
2	Theme: **General Interest.** Moderator: WARREN R. PURCELL, Rath & Strong, Inc., 80 Federal Street, Boston, Mass. Speaker: W. E. JONES, Quality Control Consultant, Management Controls, 699 Rose Ave., Des Plaines, Ill. Subject: INSTALLATION OF A QUALITY CONTROL SYSTEM. Speaker: ERVIN E. SCHIESEL, The Mattatuck Manufacturing Co., Waterbury 20, Conn. Subject: ENGINEERING STANDARDS AND TOLERANCES.	Theme: **Mechanical Assembly and Automotive.** Moderator: A. C. NORRIS, Director-Quality Control, Hudson Motor Car Co., Detroit 15, Mich. Speaker: PAUL A. ROBERT, Technical Ass't to Quality Manager, IBM Corporation, Plant I, Endicott, N. Y. Subject: QUALITY PROCEDURES PERTAINING TO COMPLEX ASSEMBLIES. Speaker: FRANCIS E. JOLLIFFE, Supervisor of Inspection, Warner Gear Division, Borg-Warner Corporation, 1106 E. Seymour Street, Muncie, Ind. Subject: QUALITY CONTROL AT WARNER GEAR.	Theme: **Aircraft.** Moderator: J. F. NESTEL, Director Of Quality Control, Avien-Knickerbocker, Woodside, N.Y. Panel: RICHARD W. TAYLOR, Project Test Pilot, Boeing Aircraft, Wichita, Kan. ROBERT C. LITTLE, Chief Test Pilot, McDonnell Aircraft Corp., St. Louis, Mo. JOSEPH ANCELONE, Staff Exp. Pilot, Chance-Vought Aircraft, Dallas, Texas. Subject: THE TEST PILOT'S ROLE IN QUALITY CONTROL. Moderator: JAMES C. McKELVAIN, Director of Quality Control, Temco Aircraft Corp., Dallas, Texas. Speaker: W. W. WILCOX, Manager of Inspection & Quality Control, United Airlines, P. O. Box 3000, So. San Francisco, Calif. Co-authored by: ALLEN M. HULL, Supervisor of Maintenance Analysis. Subject: STATISTICAL QUALITY CONTROL APPLICATION FOR IMPROVING AIRCRAFT & ENGINE MAINTENANCE.	Theme: **Business Operations.** Moderator: DALE L. LOBSINGER, Supt. Management Controls, United Air Lines, Denver 7, Colo. Speaker: GUY C. PARKIN, Director Industrial Statistical Control, Minnesota Mining & Manufacturing Co., 900 Fauquier Avenue, St. Paul 6, Minn. Subject: STATISTICAL TECHNIQUES IN PURCHASING, SCHEDULING AND SALES. Moderator: HARMON S. BAYER, Quality Control Consultant, 1154 Book Building, Detroit 26, Mich. Speaker: E. T. MACRUDER, Statistician, The Chesapeake & Potomac Telephone Companies, 725 Thirteenth St., N.W., Washington, D. C. Subject: STATISTICAL METHODS FOR APPRAISING PUBLIC UTILITY PROPERTY.
3	Theme: **General Interest.** Moderator: HARRY C. ROMIG, Hughes Aircraft, Culver City, Calif. Speaker: WILLIAM H. LESSER, JR., Supervisor of Quality Control, General Electric Company, One River Road, Schenectady 5, N. Y. Subject: COST OF QUALITY. Subject: JAMES ARMSTRONG, JR., Statistical Engineer, E. I. DuPont De Nemours & Company, Inc., P. O. Box 1477, Richmond 12, Va. Subject: SOME USES OF STATISTICS IN PLANT MAINTENANCE.	Theme: **Automotive.** Moderator: J. C. KNAPP, Superintendent Quality Control, Ford Motor of Canada, Windsor, Ont. Speaker: STEPHEN J. ROGERS, Assembly Plant, Ford Motor Co., Dearborn, Mich. Subject: RECEIVING INSPECTION SYSTEMS. Panel: LEO R. HARRINGTON, Chief Inspector, King-Seeley Corp., Ann Arbor, Mich. HARRY HAUSMAN, Chief Inspector, Budd Company, Gary, Ind. NELSON C. MEACLEY, Manager Statistical Quality Control, Willys Motors, Inc., Toledo 1, Ohio. JOSEPH P. ROCHE, Chief, Quality Control Branch, National Tank—Automotive Inspection Office, Ordnance Corps, Detroit Arsenal, Center Line, Mich. Subject: VENDOR CERTIFICATION OF QUALITY.	Theme: **Aircraft.** Moderator: H. O. WILLIAMS, Chief, Quality Control, Douglas Aircraft, Sta Monica, Calif. Speaker: COLONEL CARL F. DAMBERG, USAF, Chief, Quality Control Hq., AMC, Wright-Patterson AFB, Dayton, Ohio. Subject: THE AIR FORCE QUALITY CONTROL PLAN FOR PROCUREMENT. Moderator: JOSEPH R. SILVERMAN, Quality Control Manager, Chance-Vought Aircraft, Inc., P. O. Box 5907, Dallas, Texas. Speaker: RALPH S. READE, Chief of Engineering, Test Laboratory, Consolidated Vultee Aircraft Corp., Fort Worth, Texas. Subject: ESTABLISHMENT OF QUALITY LEVEL THROUGH COMPONENT AND SYSTEM TESTING . . . AIRCRAFT SYSTEMS AND COMPLEX ITEMS.	Theme: **Business Operations and Complex Ordnance Assemblies.** Moderator: DR. CARL E. NOBLE, Kimberly Clark Corporation, Neenah, Wis. Speaker: JOHN WAGNER, University of Colorado, Denver, Colorado. Subject: QUALITY INCENTIVE. Speaker: MAJOR GENERAL LESLIE E. SIMON, Assistant Chief of Ordnance, Washington 25, D. C. Subject: QUALITY CONTROL IN THE MANUFACTURE OF COMPLEX ASSEMBLIES.
4	Theme: **General Interest.** Moderator: PROFESSOR JOHN A. HENRY, Department of Mechanical Engineering, University of Illinois, Urbana, Ill. Panel: DR. CARL E. NOBLE, Technical Research Laboratories, Kimberly-Clark Corp., Neenah, Wis. RUDOLPH FREEDMAN, Production Superintendant, Alco Valve Co., St. Louis, Mo. FRED J. HALTON, JR., Ass't to the President, Deere & Co., Chicago, Ill. Subject: SYMPOSIUM ON INPLANT TRAINING FOR DESIGN ENGINEERS & RESEARCH WORKERS; PRODUCTION SUPERVISION; TOP MANAGEMENT.	Theme: **Automotive.** Moderator: DR. C. C. CRAIG, University of Michigan, Ann Arbor, Mich. Speaker: ARTHUR BENDER, JR., Delco-Remy Division, General Motors Corporation, 2401 Columbus Avenue, Anderson, Ind. Subject: USE OF PROBABILITY PAPER. Speaker: JAMES V. STRELA, Staff Statistician, Thompson Products, Inc., 23555 Euclid Avenue, Cleveland 17, Ohio. Subject: STATISTICAL CONTROL OF MULTIPLE OPERATIONS.	Theme: **Textile.** Moderator: CARDINER HAILES, Avondale Mills, Sylacauga, Ala. Speaker: CHARLES C. WILSON, Ass't Director, Research Division, West Point Manufacturing Company, Shawmut, Ala. Subject: TEXTILE QUALITY ANALYSIS. Speaker: ROBERT A. POSEY, Quality Control Manager, Peter Pan Manufacturing Corp., 255 Grant Ave., East Newark, N. J. Subject: QUALITY CONTROL IN GARMENT MANUFACTURING.	Theme: **New Statistical Developments.** Moderator: R. H. STEWART, Quality Manager, Lear Inc., Grand Rapids, Mich. Speaker: CALVIN J. KIRCHEN, Rec. Insp. Quality Analyst, Wayne Assembly Plant, Lincoln-Mercury Division, Ford Motor Co., Wayne, Mich. Subject: BINOMIAL PROBABILITY TABLES. Speaker: DORIAN SHAININ, Industrial Consultant, Rath & Strong, Inc., Boston, Mass. Subject: CHART CONTROL WITHOUT CHARTS—SIMPLE, EFFECTIVE COMPARATOR QUALITY PRE-CONTROL.
5	Theme: **General Interest.** Moderator: PROFESSOR ACHESON DUNCAN, The Johns Hopkins University, Charles Street, Baltimore, Md. Speaker: PROFESSOR PAUL C. CLIFFORD, State Teachers College, Montclair, N. J. Subject: VISUAL AIDS TELL THE QUALITY CONTROL STORY.	Theme: **Statistical Analysis.** Moderator: LEO J. JACOBSON, Mgr. Q. C. Dept., international Resistance Company, Philadelphia 8, Pennsylvania. Speaker: FRANK PROSCHAN, Manager-Quality Control, Sylvania Electric Products, Inc., Hicksville, N. Y. Subject: EXPERIMENTS COMPARING TWO METHODS FOR PERCENTAGE DEFECTIVE	Theme: **General Interest.** Moderator: PROFESSOR J. M. JURAN, 195 Beech Street, Tuckahoe, N. Y. Speaker: J. LESLIE LENTON, Works Manager, American Machine & Foundry Co., P. O. Box 187, Station F, Buffalo 12, N. Y. Subject: QUALITY CONTROL LOOKS AT THE FINANCIAL STATEMENT.	Theme: **Food Industry.** Moderator: H. J. JACOBSON, Chief Inspector, Grand Sheet Metals Products Co., Chicago, Ill. Speaker: FRED W. RUSSE, JR., Ass't Chief of the Quality Control Division, Bureau of Ordnance, Washington, D. C. Subject: DESIGN, DEVELOPMENT AND PRODUCTION WITH RELATION TO ACCEPTANCE INSPECTION PRACTICES.

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SERIES	E	F	G	H
PERIOD	Theme: **Metals Inspection.** Moderator: JOHN W. W. SULLIVAN, Metallurgical Engineer, American Iron & Steel Institute, 350 Fifth Avenue, New York 1, N. Y. Speaker: FRANK G. NORRIS, Wheeling Steel Corporation, Steubenville, Ohio. Subject: SURVEY OF STATISTICAL METHODS IN THE METALS INDUSTRY.	Theme: **Operations Research.** Moderator: PAUL S. OLMSTEAD, Bell Telephone Laboratories, Whippany, N. J. Speaker: DR. HAROLD O. DAVIDSON, The Johns-Hopkins University, Operations Research Office, 6410 Connecticut Avenue, Chevy Chase, Md. Subject: OPERATIONS RESEARCH CONCEPTS USEFUL IN QUALITY CONTROL.	Theme: **Paper and Printing.** Moderator: L. S. EICHELBERGER, Quality Control Staff, A. O. Smith Corp., Milwaukee 1, Wis. Speaker: EDWARD R. HOFFMAN, Statistical Quality Control, Hammermill Paper Company, Erie 6, Pa. Subject: THE HAMMERMILL QUALITY STORY.	Theme: **Plant Tour.** Anheuser-Busch Inc., Century Electric Co., Falstaff Brewing Corp.
1	Moderator: RICHARD H. EDE, Process Metallurgist, United States Steel Corp., 208 South LaSalle Street, Chicago 90, Ill. Speaker: ARTHUR P. WOODS, JR., Research Engineer, Armco Steel Corp., Middletown, Ohio. Subject: STATISTICAL METHODS APPLIED TO STEEL PLANT OPERATING DATA.	Moderator: DR. HAROLD O. DAVIDSON. Speaker: PAUL S. OLMSTEAD. Subject: QUALITY CONTROL CONCEPTS USEFUL IN OPERATIONS RESEARCH.	Speaker: W. A. MACCREHAN, Quality Engineer, Bendix Radio, Baltimore 4, Md. Subject: QUALITY CONTROL IN PRINTING.	
2	Theme: **Metals Inspection.** Moderator: J. R. BEHRMAN, Alan Wood Steel Company, Conshohocken, Pa. Speaker: W. T. ROGERS, National Tube, Division of the U. S. Steel Corp., East 28th St. and Pearl Avenue, Lorain, Ohio. Subject: CONTROL OF QUALITY STEEL TUBULAR PRODUCTS. Moderator: RUSSELL Y. BARNES, Aluminum Company of America, Atlantic Street, Bridgeport 4, Conn. Speaker: ALLIN P. DEACON, P. Eng., Cockshutt Farm Equipment, Ltd., Brantford, Ont. Subject: FOUNDRY QUALITY CONTROL FOR SHORT RUNS.	Theme: **Chemical—Experimental Designs.** Moderator: EDWIN C. HARRINGTON, JR., Industrial Statistician, Plastics Division, Monsanto Chemical Co., Springfield, Mass. Speaker: DONALD S. VILLARS, Research Scientist, U. S. Naval Ordnance Test Station, Inyokern, China Lake, Calif. Subject: REPLICATION DEGENERACY. Speaker: CUTHBERT DANIEL, Engineering Statistician, 116 Pinehurst Avenue, New York 33, N. Y. Subject: LOCATING & MEASURING THE EFFECTS OF ASSIGNABLE CAUSES.	Theme: **Electronics.** Moderator: IRVIN W. SCHOENINGER, Globe-Union, Inc., 900 East Keefe Avenue, Milwaukee 1, Wis. Speaker: FRANK CAPLAN, JR., Supervisor-Process Quality Control, General Electric Company, Syracuse, N. Y. Subject: STATISTICAL DESIGN IN ELECTRONICS PRODUCTION-LINE EXPERIMENTATION. Speaker: LEO J. JACOBSON, Mgr. Quality Control Dept., International Resistance Company, 401 North Broad Street, Philadelphia 8, Pa. Subject: SOME CONSIDERATIONS IN THE EVALUATION OF ELECTRONIC COMPONENTS WITH SPECIAL REFERENCE TO RESISTORS.	Theme: **Advanced Theory Sessions.** Moderator: PROFESSOR IRVING W. BURR, Purdue University, Lafayette, Ind. Speaker: C. R. HICKS, Purdue University, Lafayette, Ind. Subject: FUNDAMENTALS OF ANALYSIS OF VARIANCE. Speaker: R. L. ANDERSON, University of North Carolina, Chapel Hill, N. C. Subject: COMPONENTS OF VARIANCE AND MIXED MODELS.
3	Theme: **Metals Inspection.** Moderator: NORMAN R. MOSS, Firth Sterling Steel & Carbide, McKeesport, Pa. Speaker: HAROLD L. SPRINGER, Metallurgical Analyst, St. Joseph Lead Co., Box 97, Monaca 7, Pa. Subject: QUALITY CONTROL IN THE MANUFACTURE OF ZINC—TECHNIQUE OF APPROXIMATING A THREE-VARIABLE PROBLEM SOLUTION. Moderator: JOHN F. OCCASIONE, Staff Metallurgical Engineer, American Steel & Wire, Division of United States Steel Corp., Rockefeller Building, Cleveland 13, Ohio. Speaker: LEON W. THELIN, Quality Supervisor, Chase Brass & Copper Company, Waterbury, Conn. Subject: CONTROL OF QUALITY OF BRASS STRIP.	Theme: **Chemical—Analytical Precision and Specifications.** Moderator: PROFESSOR E. R. OTT, Rutgers University, New Brunswick, N. J. Speaker: RAYMOND L. THATCHER, Manager Quality Control Division, E. R. Squibb & Sons, Division of Mathieson Chemical Corp., Georges Road, New Brunswick, N. J. Subject: VARIABILITY PROBLEMS IN THE PHARMACEUTICAL INDUSTRY. Speaker: MARNARD S. RENNER, Dewey and Almy Chemical Co., 62 Whittemore Avenue, Cambridge 40, Mass. Subject: THE ROLE OF STATISTICAL QUALITY CONTROL IN TODAY'S CHEMICAL COMPANY.	Theme: **Electronics.** Moderator: M. E. KING, Quality Control Div., Bureau of Ordnance, Navy Dept., Washington, D. C. Speaker: THOMAS LUCAS, Centralab Radio Products, 900 East Keefe Avenue, Milwaukee 1, Wis. Subject. FREQUENCY DISTRIBUTION ANALYSIS OF TIME STUDY DATA ON PRINTED CIRCUITS. Speaker: NELLO CODA, Chief Electrical Engineer, Erie Resistor Corp., Erie 6, Pa. Subject: A CHIEF ENGINEER EVALUATES STATISTICAL METHODS.	Theme: **Plant Tour.** Anheuser-Busch, Inc., Century Electric Co., Chevrolet-St. Louis Division General Motors Corp., Continental Can Co., Inc., Elder Manufacturing Company, Falstaff Brewing Corp.
4	Theme: **Metals Inspection.** Moderator: D. H. W. ALLAN, Metallurgical Department, The Steel Company of Canada, Limited, Hamilton, Ont. Speaker: To Be Announced Subject: To Be Announced Moderator: PHILLIPS WHIDDEN, Staff Statistician, Aluminum Company of America, Pittsburgh 19, Pa. Speaker: SAUL GILBERT, United States Steel Corp., Research & Development Laboratory, 234 Atwood Street, Pittsburgh 13, Pa. Subject: APPLICATIONS OF STATISTICAL DESIGNS TO RESEARCH PROBLEMS FOR THE STEEL INDUSTRY.	Theme: **Chemical—Continuous Processes—Sampling & Control.** Moderator: C. A. BICKING, Department of Army, Washington, D. C. Speaker: DR. JOHN T. WALTER, School of Business Administration, University of Pittsburgh, Pittsburgh 13. Subject: STATISTICAL QUALITY CONTROL IN A PETROLEUM REFINERY. Speaker: DR. W. H. WHITE, Research Department, Imperial Oil Limited, Sarnia, Ont. Subject: APPLICATIONS OF STATISTICAL METHODS TO THE CONTROL OF REFINERY OPERATIONS.	Theme: **Precision Manufacturing.** Moderator: WILLIAM E. SPENCER, Allison Division of G.M.C., Indianapolis 6, Ind. Speaker: E. J. SCHALLER, Inspection Manager, Elgin National Watch Company, Lincoln Division, 900 North 16th Street, Lincoln 1, Neb. Subject: QUALITY CONTROL IN PRECISION MANUFACTURING. Speaker: CHARLES J. HUDSON, Quality Consultant, Miniature Precision Bearings, Inc., Keene, N. H. Subject: QUALITY CONTROL IN MINIATURE BEARING MANUFACTURING.	Theme: **Advanced Theory Sessions.** Moderator: PROFESSOR IRVING W. BURR, Purdue University, Lafayette, Ind. Speaker: K. A. BROWNLEE, University of Chicago, Chicago, Ill. Subject: CONFOUNDING AND FRACTIONAL REPLICATION. Speaker: IRVING W. BURR. Subject: ANALYSIS OF COVARIANCE.
5	Theme: **Metals Testing.** Moderator: EDWARD B. HADEN, Quality Control Manager, The Esterbrook Pen Co., Camden 1, N. J. Speaker: V. E. LYSAGHT, Sales Manager, Wilson Mechanical Instrument Division, American Chain & Cable Company, Inc., Bridgeport, Conn. Subject: HARDNESS TESTING.	Theme: **Chemical—Batch Processes—Sampling and Control.** Moderator: DR. CARL E. NOBLE, Technical Research Laboratories, Kimberly-Clark Corporation, Neenah, Wis. Speaker: JOHN D. HINCHEN, Quality Supervisor, Plastics Division, Monsanto Chemical Company, P. O. Box 1531, Springfield 2, Mass. Subject: CORRELATION ANALYSIS IN BATCH PROCESS CONTROL.	Theme: **Business Operations.** Moderator: MARTIN A. BRUMBAUGH, Director of Statistics, Bristol Laboratories, Inc., Syracuse 1, N. Y. Speaker: CLAUDE S. BRINEGAR, Union Oil Company, 617 West Seventh Street, Los Angeles, Calif. Subject: DEPARTMENT STORE USES OF STATISTICAL QUALITY CONTROL.	Theme: **Plant Tour.** Carter Carburetor Corp., Century Electric Co., Chevrolet-St. Louis Division General Motors Corp., Elder Manufacturing Company, Magic Chef, Inc.

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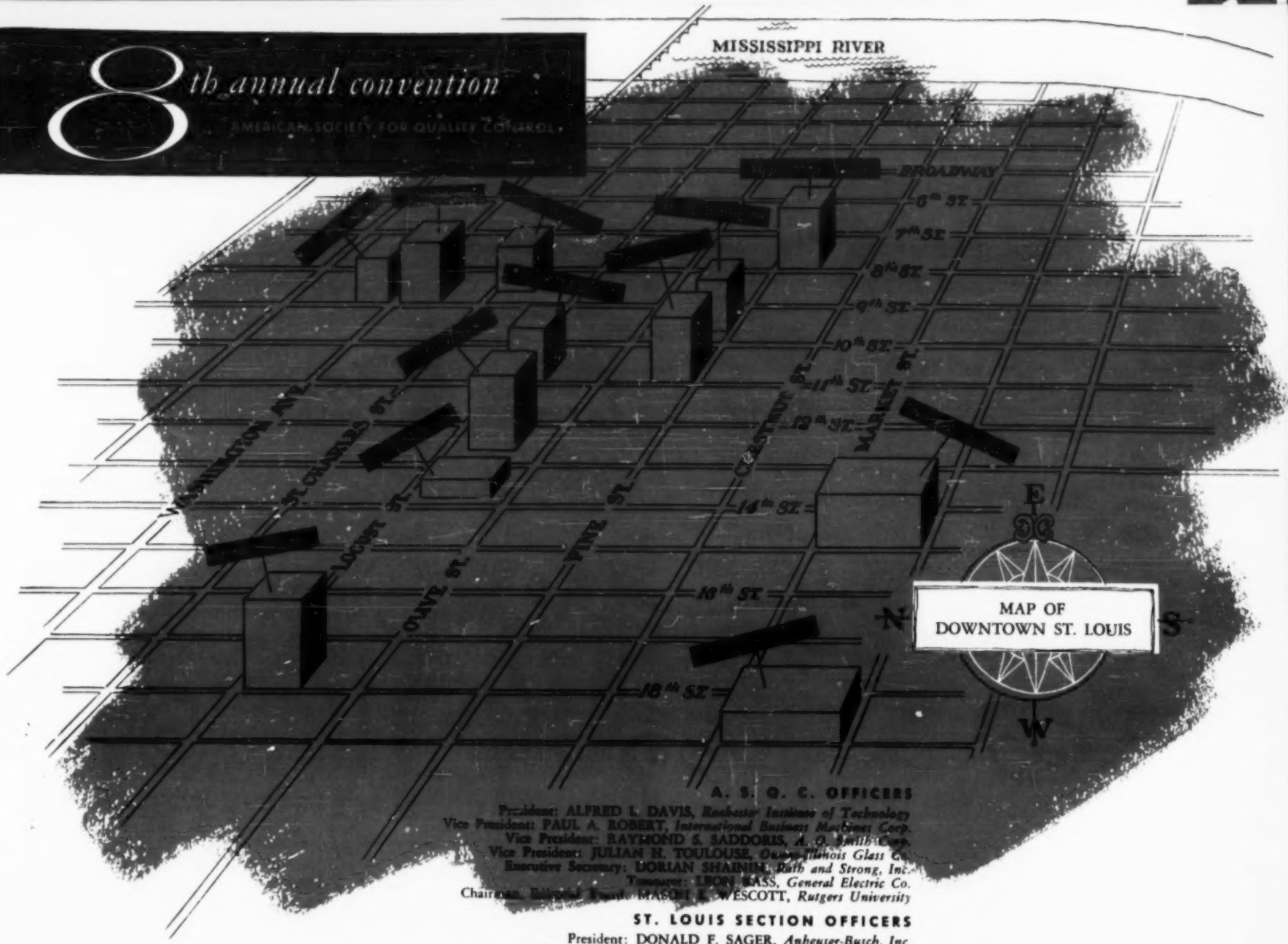

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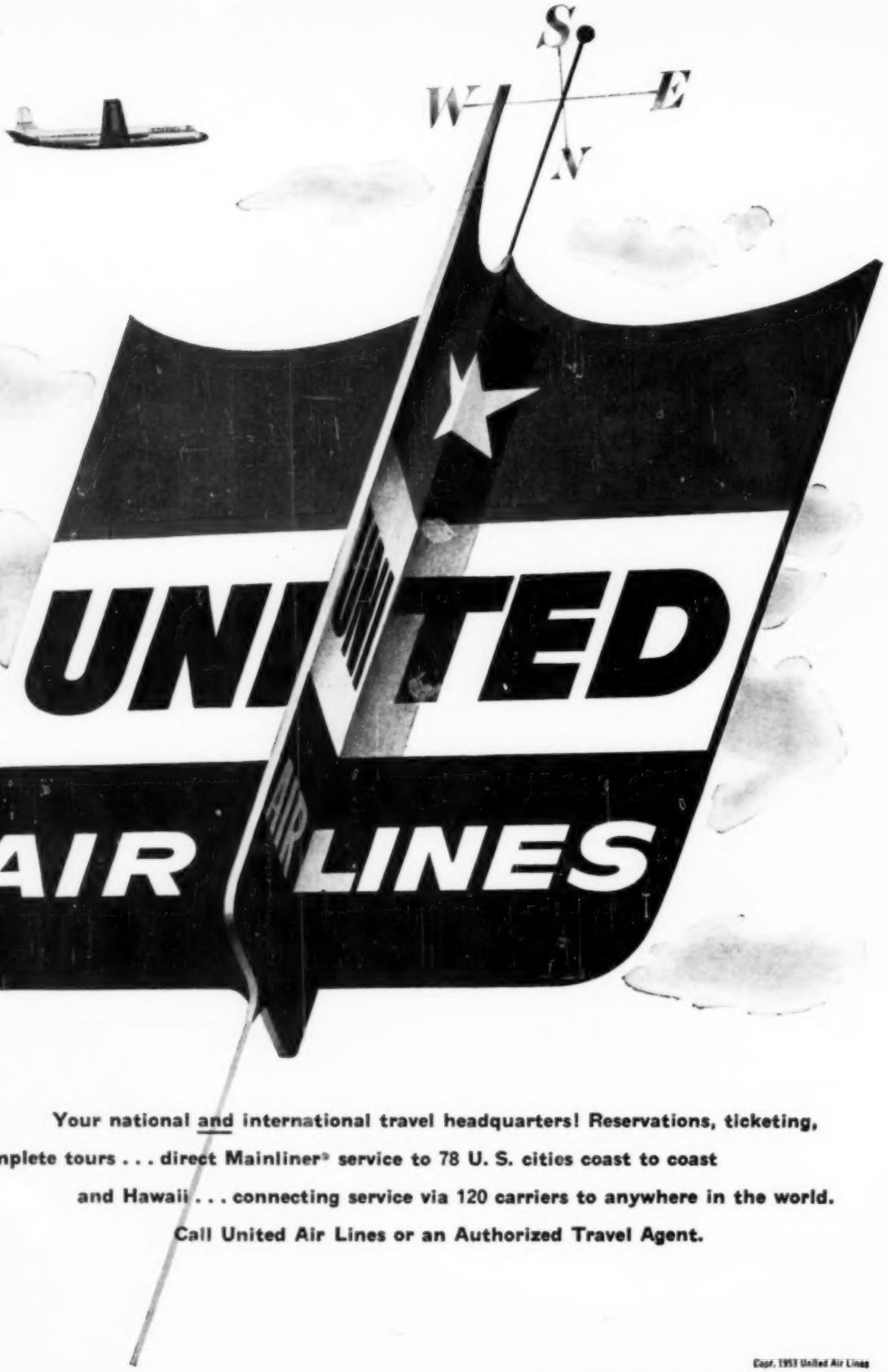

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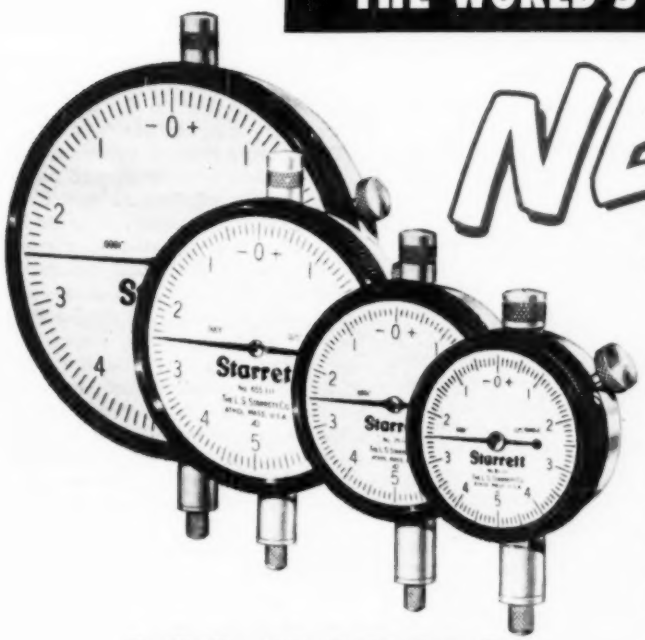

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A Statistical Study of an Assembly Problem

FRANK WEEKS, JR.

Allison Division, GMC

Many situations will arise in investigational work that would be difficult to solve properly without an overall statistical approach and analysis of the facts. The different methods employed need not involve higher mathematics, nor will a most elementary knowledge suffice. The secret to many answers seems to be in the methods and manner in which many statistical tools are used and related. It is hoped that the explanation of the following case study will further the applications of statistical methods to tolerance problems.

Blower assembly X is produced in our operations, and is the scavenging air supplying unit for Diesel locomotive train engines. The rotors of the blower assembly are required to have a specified amount of end thrust, or "play", for proper operation. This was established as 0.002 to 0.0035 in. It is important to note that this specification was introduced after some operating difficulty had been experienced.

The new specification seemed justified, but immediately caused our manufacturing unit to experience abnormal rework. Numerous remedies were tried and all seemed to fail. Production employed two hourly workers full time to perform the necessary rework. This consisted of several steps.

1. Loosening nuts holding timing gear
2. Loosening bolts
3. Removing gear
4. Pressing hub from spline of rotor shaft
5. Removing bearing, if necessary
6. Selecting and replacing either timing gear hub, or bearing
7. Reassembling, reversing the procedures above

Two major parts had more affect on the amount of end thrust than any other cause. These parts, illustrated in Fig. 1, were

1. Gear Hub—1.9970 to 1.9980 in.
2. Bearing Assembly — 1.9920 to 1.9940 in.

Our first attempt to solve the problem was to analyze the existing process. To assure that data were correct, we selected a series of measurements from the first group available for us to observe personally. This also gave us time to become more familiar with the techniques of the assembly process. Figure 2 illustrates the results of this first study. Not only was the distribution of the end-thrust process considerably spread out beyond the specifications, but there seemed to be a tendency for the thrust measurements to skew, or tail out toward the low limit. It was also noticed that the thrust measurements would occur in groups, or "families", within the total distribution. This indicated to us that some particular causes were operating which were artificially created, thus preventing chance causes from functioning properly.

The next step taken was to determine the process capabilities of each of the two major parts. This seemed logical, as we wanted to know if the process was in a state of statistical control, and if the specifications were being maintained. Figure 3 indicates the distribution curves of the measurements of hubs and bearings. The process for the gear hub was machining properly, and although a small number would appear now and then on the high side, it was considered satisfactory.

The bearing process, however, was found to have a small enough natural tolerance relative to specification requirements so that it could be operated safely at several different levels within the total tolerance band, and this, in fact, was exactly what was happening. We were thus led to believe that one reason for the wide spread of the assembly distribution of end-thrust measurements was the combination of hubs with bearings produced at various levels; i.e. the end-thrust distribution was being inflated by the wandering of the bearing process level within its tolerance band.

It was first our desire to determine why assembly of the parts produced under existing conditions did not result in thrust amounts within specifications. A comparison of blueprint tolerances was made as follows:

Hub	1.9970"	Low Limit
Bearing	1.9940"	High Limit
	0.0030"	Min
Hub	1.9980"	High Limit
Bearing	1.9920"	Low Limit
	0.0060"	Max

The 0.003 to 0.006 in. which could theoretically be attained did not in any way correspond to the 0.002 to 0.0035 in. specification. This was explained as due to many factors.

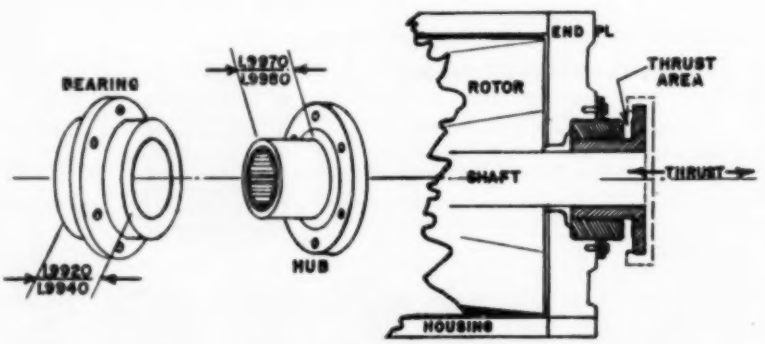

Figure 1—Blow-up Diagram of the Hub and Bearing Portion of the Blower Assembly

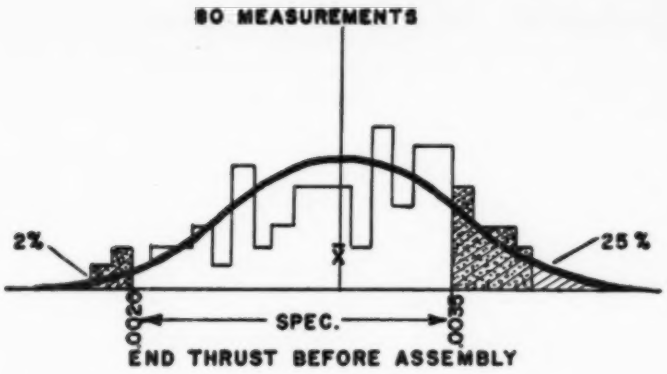

Figure 2—Histogram of End Thrust Measurements at Beginning of Investigation

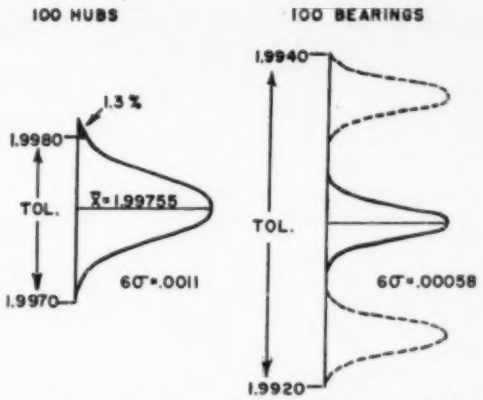

Figure 3—Separate Distributions of Hubs and Bearings

other than the hub and bearing, which affected the amount of end thrust obtained, such as parallelism of housing end faces, squareness of end faces of housing with bore, flatness of end plate, and other causes which were considered natural and tolerable. Since we were experiencing thrust loss due to the assembly of parts, how much loss was occurring?

This led us to the next phase of our investigation, and one of the most important. Shop personnel knew that thrust loss was experienced, but no one seemed to know accurately how much, and we received answers of from 0.001 to 0.003 in. Fifty hubs and bearings were consequently measured for the amount of thrust before and after assembly. Figure 4 shows the correlation chart of the results. It was easy to determine from this scattergram the amount of end thrust needed before assembly, viz, 0.0034 to 0.0051 in.

Let us mention at this point that prior to our investigation it had been decided to separate the tolerances of each part into three classes, or groups. The parts in each class were stamped "High", "Medium", or "Low". After reaching assembly, such parts were then correspondingly matched. After we had compared the 0.0034 to 0.0051 in. thrust needed before assembly with the amounts which should have been obtained under the selective fitting system, it was seen that many end-thrust amounts would be acceptable, and there should not have been the amount of rework we were experiencing.

The reason was uncovered when we selected hubs and bearings which had already been inspected and stamped, and then measured them for accuracy. It was disclosed that approximately 20 percent of the parts could be considered in the wrong classification. This would seem to reflect on the accuracy of the inspection group, but such was not the case in its entirety. The squareness of the bore with the thrust face (on both parts) consumed much of the tolerance allowed, and due to the method of measurement, could result in a discrepancy in readings of from 0.0001 to 0.0006 in. Remember that this incorrectness was in classifying into each of the three groups within the tolerance, and not in acceptance of the parts outside tolerance. Accurate classification was not practical under the existing conditions; it only contributed adverse affects to the whole problem.

It was suggested that the answer lay in an improvement in inspection methods, or better gaging. Our thinking, however, was along the lines of not only reducing rework, but eliminating the classifying and allowing chance causes to function. The solution was sold on the basis of "let us show you the results."

Our main problem was how to obtain the desired 0.0034 to 0.0051 in. end thrust before assembly, so that we could make random rather than selective assemblies. Since we knew the process capabilities for both the hub and bearing operations, the solution was expected to come from there. It was decided to accept the natural spread of the hub process as satisfactory, and to establish 1.9981 in. as the upper process limit. Our rework problem would not be relatively affected by the few pieces which would occur above 1.9981 in. The bearing process could

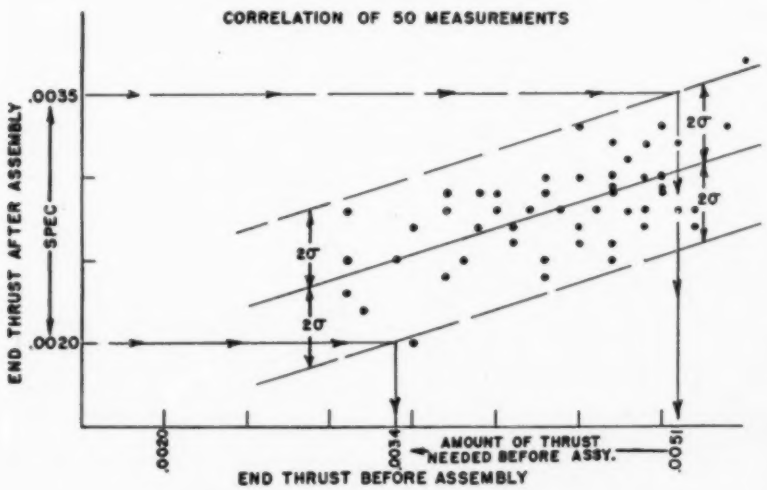

Figure 4—Correlation Between End Thrust Before and After Assembly

be run at several different levels, and it remained for us to determine where. A comparison of the hub process limits with the maximum and minimum end thrust needed before assembly would give us the desired information.

Hub 1.9981"	High Process Limit
−.0051"	Maximum End Thrust
1.9930"	Lower Limit for Bearing
Hub 1.9970"	Low Process Limit
−.0034"	Minimum End Thrust
1.9936"	Upper Limit for Bearing

Thus, any combination of hubs produced as always, and bearings run at 1.9930 to 1.9936 in., should result in sufficient end thrust after assembly.

The desired authority for the first parts assembled under the new concepts was obtained, and the trial period began. The results were satisfactory, indeed they were almost amazing. Figure 5 shows the distribution of end thrust measurements after the investigation. Our recommendations were adopted. In all fairness we must say that this situation did not occur suddenly, as a considerable period of time elapsed during which parts previously produced were used in assembly.

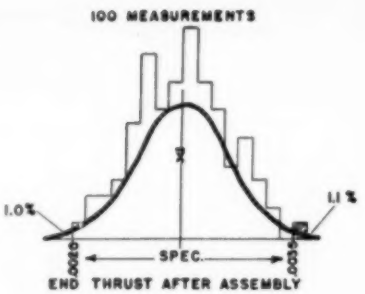

Figure 5—Histogram of End Thrust Measurements at Conclusion of Investigation

To summarize, this was a situation which adopted a way of thinking in relation to the data available. It is true that certain techniques were used, such as simple frequency histograms and correlation chart studies. But such items as the coefficient of correlation and significance tests were not needed or used. The main point is that the problem was solved by the driving theme of distribution relationships.

Our results from the entire project are as follows:

Before SQC
Average No. Reworks 20 out of 50
Selection by Inspection
Mating parts by Production

After SQC
Average No. Reworks 1 out of 50
Selection eliminated
Mating eliminated
Rework Reduction 95.2%

Editorial Note:

The referee suggests the following approach as a logical alternative to the methods used by the author and his associates:

Let
X = Hubs: 1.9970 to 1.9981 in.
"natural tolerance" = 0.0011 in.
Z = End Thrust: 0.0034 to 0.0051 in. needed
The mean of this is 0.00425 in.
Y = Bearings: "natural tolerance" = 0.0006 in.
Means adjustable
X − Y = Z end thrust before assembly.

Then

$$\bar{X} - \bar{Y} = \bar{Z}$$

$$1.99755 - \bar{Y} = 0.00425$$

or

$$\bar{Y} = 1.9933 \text{ in.}$$

So set specs for bearings at:

$$1.9933'' \pm 0.0003'' = 1.9930'', 1.9936''$$

Since

$$\sigma_{X-Y} = \sqrt{\sigma_X^2 + \sigma_Y^2}$$

or

$$3\sigma_{X-Y} = \sqrt{(3\sigma_X)^2 + (3\sigma_Y)^2}$$

$$= \sqrt{\left(\frac{0.0011}{2}\right)^2 + \left(\frac{4.0006}{2}\right)^2}$$

$$= 0.00063 \text{ in.}$$

the specs on end thrust should now be able to meet 0.00425" ± 0.00063" = 0.0036", 0.0049" which is considerably better than the 0.0034", 0.0051" adopted.

In accepting the referee's suggestion the author makes this interesting comment:

"This (the referee's analysis) would account for end-thrust rework being somewhat less in the past year than calculations based on my solution indicated they would be."

The paper is published as a record of how the problem *was* solved satisfactorily by the men who did the work.

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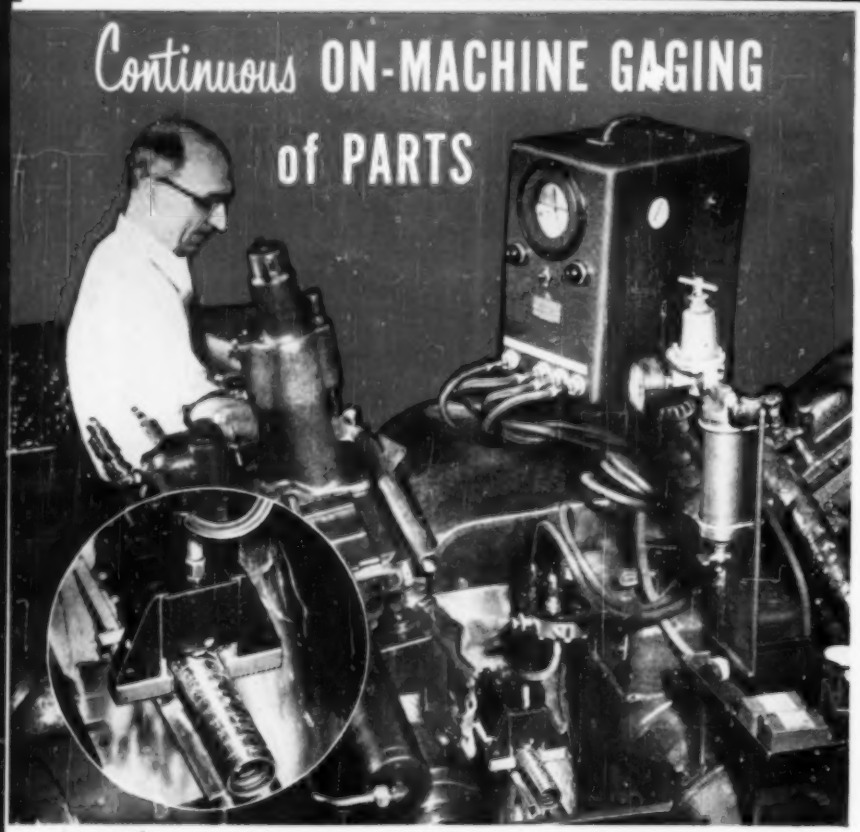

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Despite recent developments in some fields, the completely automatic factory . . . with raw materials fed into one end of a mile-long transfer machine and finished products emerging from the other . . . is something in the rather distant future for most manufacturers. However, Automatic Process Control (which will be a vital *part* of eventual complete automation) is just around the corner. For thousands of manufacturers it will soon provide the immediate, practical answer to industry's need to produce more accurate parts faster and at lower cost.

SELF-CORRECTING MACHINES ARE NEXT

Automatic "self-operating" machines are now in common use; tomorrow these machines will be "*self-correcting*" as well. Pratt & Whitney Gages, for example, have already been applied to many types of machining and other operations to provide automatic, in-process gaging. All that remains is to provide a "feed-back" from the gage to the machine to effect corrections automatically. The P&W Gages and Control Units to accomplish this are now available, and Pratt & Whitney is working in close cooperation with several machine manufacturers to develop modifications in machines that will permit adjustment by gage-activated means rather than by hand.

SUCCESSFUL INSTALLATIONS ALREADY EXIST

While widespread availability of self-correcting machines must depend on further developments, there are some installations already in highly successful operation. Pratt & Whitney Control Units are being used in con-

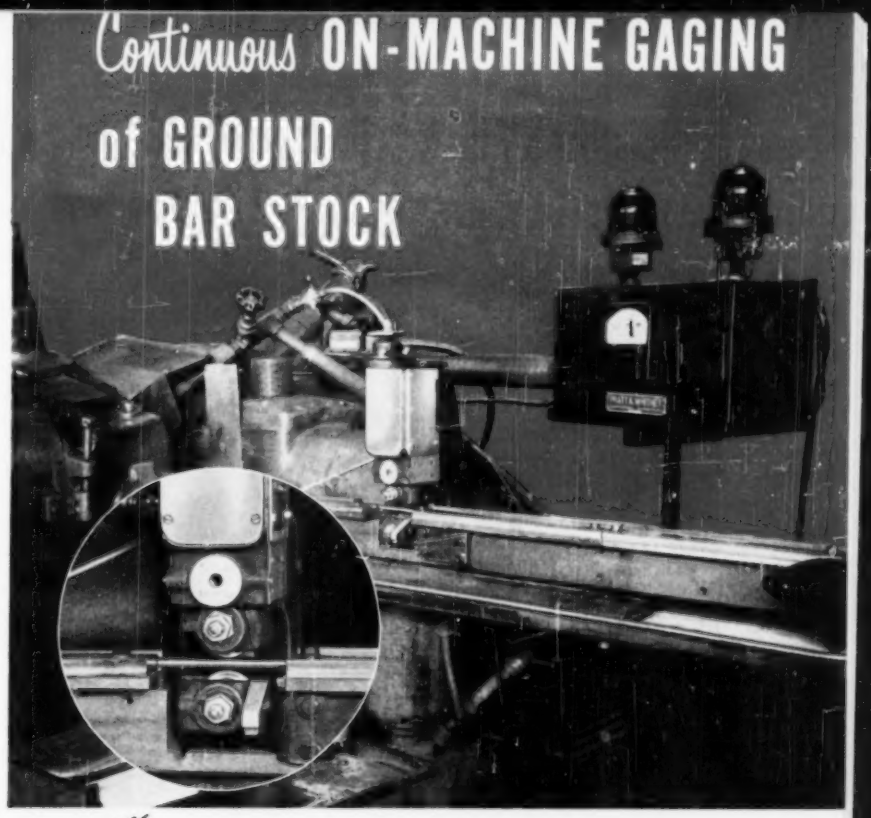
junction with P&W Continuous Gages to provide screwdown control that automatically corrects variations in thickness of steel being cold rolled. Similar installations automatically correct the thickness of plastic coating on extruded wire. Many other types of installations are now being engineered and will soon be in operation.

ADVANTAGES ARE MANY

The advantages of self-correcting machines are many and important. Production rates are greatly increased without sacrificing accuracy; even where extreme precision is the primary consideration, greater volume and more reliable accuracy are obtained. Corrections are made without stopping the machine, thus nonproductive periods are eliminated and further increases in overall volume are realized. Rejects are greatly reduced. Gaging as a more expensive separate operation is eliminated. Where a permanent inspection record is required, automatic recording devices are readily incorporated.

HISTORY-MAKING GAGES SHOWN AT QUALITY CONTROL SHOW

Several of the gages that are now making self-operating machines a practical reality . . . and many others in the complete Pratt & Whitney Line . . . can be seen at Pratt & Whitney Booth No. 61-62 at the American Society for Quality Control Show. Included will be the newly developed synchro-transfer signal control, the new Model D Universal Internal Comparator, Air-O-Limit and Electrolimit Internal and External Clearance Calculators with Differential Computors, the new Model G Air-O-Limit Comparator, and the recently re-designed Millionth Comparator that incorporates such important improvements as a new 4-Way Magnification Switch that provides even greater versatility. Pratt & Whitney Gage Engineers will be on hand to explain all equipment and discuss individual gaging problems. Also at the Show . . . a complete display of P&W conventional gages.



with

PRATT & WHITNEY
Electrolimit Gages

Developed originally for cold rolling mills, the Pratt & Whitney Electrolimit Model D Gage is here applied to continuous, on-machine gaging of precision, centerless ground bar stock. The P&W Light Signal Control with meter u. d in conjunction with the gage, gives a continuous, accurate reading; light signals indicate oversize or undersize. Important benefits include:

- **BETTER CONTROL OF GRINDING ACCURACY** . . . with immediate correction of machine before work is spoiled.
- **FASTER PRODUCTION** . . . operator continuously sees size variations due to wheel wear and makes corrections during grinding.
- **GREATER OPERATOR CONVENIENCE** . . . indicating meter is easy to read; corrections are easier, faster. Extra gaging operations are eliminated.

SEE THE ELECTROLIMIT GAGE at the A.S.Q.C. SHOW
ST. LOUIS, JUNE 9-12 — BOOTH 61-62

Our Gage Engineers will be on hand to give you complete information and show you how P&W can help solve your specific gaging problems.

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DIVISION NILES-BEMENT-POND COMPANY
WEST HARTFORD 1, CONNECTICUT, U. S. A.
SINCE 1860

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MACHINE TOOLS • CUTTING TOOLS • GAGES

Electronic Magic

...working to improve farming's future!

INSIDE THE "TRAVELAB"

A Ford research engineer watches as stress and strain pulses are flashed electronically to oscillographs, that record the whole story on graph paper. The mobile laboratory is a self-sufficient unit, equipped with a telephone system for communication among test members, and ultra-high speed motion picture equipment.

Farm implements "write" their own success stories electronically in a new technique used by Ford Tractor research engineers to design better tools for better farming.

A mobile stress and strain laboratory, called the "Travelab," field tests the Ford Tractor and Dearborn Equipment in varying soil conditions across the country. Equipped with the most advanced electronic instruments, it measures and records the stresses and strains in implements at work. By interpreting electronically-written graphs, engineers have positive facts to use in checking farm implement design.

The "Travelab" can be used with any type of farm equipment—from plows and cultivators, to cotton harvesters and hay balers. And it can test this equipment almost anywhere—in Georgia clay, Iowa loam, or Texas sand.

This new mobile laboratory is just one phase of an intensive agricultural research program being carried on by Ford engineers to provide the equipment farmers will need in the years to come . . . equipment that will further ease the farmer's burdens and increase his profits.

TRACTOR AND IMPLEMENT DIVISION
FORD MOTOR COMPANY
Birmingham, Michigan

Ford TRACTOR

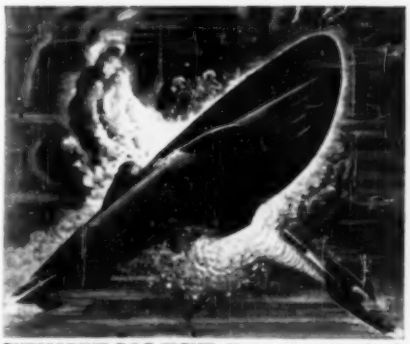
Ford Farming MEANS BETTER WORK... MORE INCOME PER ACRE

balanced diet for Diesels

DIESELS star on man-sized jobs like bulldozing mountains into molehills. And the tougher the job, the more important it is for Diesels to have a balanced diet . . . precise quantities of fuel, accurately measured and pumped to each cylinder with split-second timing.

Most Diesel engine manufacturers select American Bosch fuel injection systems for this precision job. Just as the American Bosch name has long been the standard of performance for automotive electrical equipment, today it also means engineering leadership in fuel injection systems in the rapidly expanding Diesel power field.

Emphasis on research, engineering, and precision manufacture are basic policies of the progressive American Bosch management. Arma Corporation, a subsidiary, also fulfills this forward-looking thinking through its continuing development of the most advanced systems in electronic controls and devices for the Armed Forces.



SUBMARINE DOG FIGHT. Electronic systems developed and produced by Arma Corporation for the Army, Navy, Air Force and Atomic Energy Commission promise interesting future industrial application.

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What's Your IQ in QC

R. O. SWALM **C. R. HICKS***

Syracuse University

Have you ever wondered how your knowledge of quality control compares with that of others in the same field? You can find the answer to that question in just 15 min. by taking the quiz which was offered first as a surprise feature of the Society's 1952 Convention. The quiz was presented as an interesting experiment in self-evaluation and in that spirit it is here offered to our entire membership.

You will find that the questions range from very easy to quite difficult. Do not become discouraged if you are in doubt as to many of the answers. When in doubt guess, (let the laws of chance help you) and go on to the next question. Allow yourself 15 min. You will find the correct answers and an analysis following the quiz. Good luck!

---

1. A p chart is used when data consist of:
   a) Variables b) Attributes c) Standard Deviations d) weights

2. Dues of our society become payable in the:
   a) Spring b) Summer c) Fall d) Winter

3. The sum of the deviations of a group of measures from their mean divided by the number of measures equals:
   a) σ b) σ^2 c) Zero d) $\bar{X}$

4. The president of the ASQC this year is:
   a) Walter Shewhart b) Simon Collier
   c) Wade Weaver d) Alfred Davis e) Leon Bass

5. Standard deviation may be correctly called:
   a) Mean square deviation b) Average deviation
   c) Root-mean-square deviation d) Probable Error

6. Control charts were first devised by:
   a) Juran b) Grant c) Dodge and Romig
   d) Shewhart

7. The first widely used double-sampling tables were devised by:
   a) Brumbaugh b) Shewhart c) Dodge and Romig
   d) Simon

8. $\bar{X}$ control charts to examine the variation between averages of samples can be drawn by plotting:
   a) Subgroup totals c) Subgroup sigmas
   b) Subgroup ranges d) Subgroup size

9. The award for the best article in *Industrial Quality Control* for the year is the:
   a) Shewhart Medal c) Congressional Medal of Honor
   b) Fisher Award d) Brumbaugh Award

10. MIL-STD-105A is used for:
    a) Establishing control limits b) Setting tolerances
    c) Accepting material d) Inspecting threads

11. If drawing tolerances and the natural tolerances of a process operating under the normal law are the same, the control limits for $\bar{X}$ will be:
    a) The tolerance limits b) The tolerance limits times n
    c) The tolerance limits divided by n
    d) The tolerance limits divided by $\sqrt{n}$

12. A.O.Q.L means:
    a) Average outgoing quality level b) Average outgoing quality limit c) Average outside quality limit
    d) Anticipated optimum quality level

13. An elementary presentation of analysis of variance can be found in:
    a) Grant's "Statistical Quality Control"
    b) Simon's "An Engineer's Manual of Statistical Methods"
    c) Z 1.3
    d) Back issues of *Industrial Quality Control*

14. A p chart based on samples taken from each box of a large shipment of parts can be used to test:
    a) The homogeneity of the shipment
    b) Whether or not the parts are produced under control
    c) Whether or not the parts are in specification
    d) None of these

15. It is often economical to permit $\bar{X}$ to go out of control when:
    a) Individual R's exceed $\bar{R}$
    b) Cost of inspection is high
    c) 6 σ' is appreciably less than the difference between specification limits
    d) The $\bar{X}$ control limits are inside the drawing tolerance limits

16. When measurements show a lack of statistical control, the standard error of the average:
    a) Is related to confidence limits
    b) Is a measure of process variability
    c) Is simple to compute d) Has no meaning

17. The factor(s) for determining the 3-σ control limits for an $\bar{X}$ chart from σ is (are):
    a) A_1 b) A_2 c) B_1 and B_2 d) D_3 and D_4

18. When incoming material is inspected by go not-go gauges, a group sequential sampling plan will:
    a) Prevent acceptance on the first sample
    b) Never require more sampling than a single-sampling plan
    c) Always be inferior to double sampling
    d) Give the most flexible sampling consistent with the quality of the material

19. A cumulative frequency distribution is called:
    a) An operating characteristic b) A histogram
    c) An ogive d) A frequency polygon

20. Probability paper can be used:
    a) To inspect a distribution for normality
    b) For control charts
    c) To reduce the importance of extreme values
    d) None of the above

21. Consumers risk of 10% means that:
    a) The probability that a sampling plan will reject "good" material is 10%

*Dr. Hicks is now at Purdue University, Lafayette, Ind.

b) The probability that a sampling plan will accept "poor" material is 10%
c) The acceptable quality level of the lot is 10%
d) The unacceptable quality level of the lot is 10%

22. The basic purpose of control charts for $\bar{X}$ and R can be accomplished equally well by:
a) A "t" test
b) An "F" test
c) Analysis of variance
d) Multiple Regression

23. As compared to a single point outside either 3 σ limit, two points in succession outside the same 2 σ limit on the control chart for $\bar{X}$ are:
a) A more significant indication of an assignable cause
b) An equally significant indication of an assignable cause
c) A less significant indication of an assignable cause
d) Unimportant

24. In the Poisson distribution, the standard deviation is:
a) $\sqrt{pq}$ b) $\sqrt{\Sigma pq}$ c) $\sqrt{c'}$ d) None of these

25. If nothing is known concerning the pattern of variation of a set of numbers, we can calculate the standard deviation of the set of numbers and state that $\bar{X} \pm 3\sigma$ will include at least:
a) 89 percent of all the numbers
b) 95 percent of all the numbers
c) 99.7 percent of all the numbers
d) None of these

26. When A and B are distributed normally and independently, σ_{A-B} is equal to:
a) $\sigma_A + \sigma_B$ b) $\sigma_A - \sigma_B$
c) $\sqrt{\sigma_A^2 + \sigma_B^2}$ d) $\sqrt{\sigma_A^2 - \sigma_B^2}$

27. If the distribution of defectives among various lots is found to follow the laws of chance, we can conclude that:
a) The manufacturing process was in control
b) The product was well mixed before dividing into lots
c) Either (a) *or* (b) is true
d) All lots should be accepted

28. The probability of drawing at random exactly one defective in a sample of 5 from a lot of 50 containing 20 percent defectives is
C_5^{50} divided into:
a) $C_{50}^{49} C_1^5$ b) $C_{20}^{40} C_1^5$
c) $C_4^{40} C_1^{20}$ d) $C_4^{40} C_1^{10}$

29. If three blocks are to be assembled by placing them on top of each other and if the height of each block is specified on the component part drawing as 1.000" ± .015", we can expect the difference in height between the largest and smallest of 100 such assemblies to be nearest to:
a) 0.030"
b) 0.060"
c) 0.090"
d) More information is needed before an answer can be given

30. In setting up a control chart for a certain process, σ' is found to be 11 units. Repeated measurements of the same part using the same technique on which the chart is based show a standard error of measurement of 5 units. The best estimate of the true standard deviation of the *process* is nearest to:
a) 6 units
b) 10 units
c) 11 units
d) 12 units

Here are the correct answers to the quiz.

1 b	11 d	21 b
2 b	12 b	22 c
3 c	13 d	23 a
4 d	14 a	24 c
5 c	15 c	25 a
6 d	16 d	26 c
7 c	17 a	27 c
8 a	18 d	28 d
9 d	19 c	29 d
10 c	20 a	30 b

IF YOUR SCORE IS FROM:	YOUR KNOWLEDGE OF QUALITY CONTROL IS:
0 to 6	Poor—Better sign up for a basic course in Quality Control.
7 to 11	Fair—But you might consider rereading one of the basic texts such as Grant's.
12 to 17	Good—Have you considered a senior membership in the society?
18 to 22	Very good—Perhaps you should ask for a raise.
23 to 30	Excellent — Have you ever considered writing a book?

How do we get these ratings? How reliable are they? And how about the questions on the quiz—aren't some of them pretty poor? Thanks to the splendid cooperation of the delegates to the 1952 Convention, the answers to these questions are now available, and since the determination of the answers illustrates the way that test makers use the same sort of statistics we apply to Quality Control problems, a brief consideration of the answers and how they are obtained may be of interest.

Perhaps the first thing that should be said is that, compared to the traditional test in which 60 to 70 percent is a passing grade, this is a quiz designed on the principle of a test of increased severity. In order to differentiate more accurately between various levels of ability the test was designed to yield an average score of about 15 correct (or 50 percent). How well did we succeed? Well, we were lucky—the average for the 851 turning in answer sheets at the convention was 14.4. The standard deviation of scores was 5.4, and the classification listed above are based on the following:

Over 1½ Standard deviations below the mean—Poor.

From 1½ to ½ Standard deviations below the mean—Fair.

From ½ below to ½ Standard deviation above the mean—Good.

From ½ to 1½ Standard deviations above the mean—Very Good.

Over 1½ Standard deviations above the mean—Excellent.

Incidentally a rough check on the normality of the distribution of scores is given by the following data:

	ACTUAL	THEORETICAL
% of scores within ± 1 sigma	67%	68%
% of scores within ± 2 sigma	96%	95%
% of scores within ± 3 sigma	100%	100%

So you see people are normal, even at conventions.

But is the test itself a reliable instrument? Are some of the questions poor? Again statistics can help give us the answers. In examining the worth of each individual question we will use two guiding principles. The first of these is that in order to discriminate most effectively between abilities throughout their entire range, the test items should range in difficulty from quite easy to very difficult—ideally at equal increments of difficulty. The second is that each item should be useful in selecting superior from inferior ability in the field being measured. The technique of examining each item in the light of these principles is called item analysis. In order to perform this analysis we chose a random sample of 200 papers out of the 851 turned in and divided these into halves on the basis of the scores. Then, with the help of our wives, we made a tally of the number of respondents in each half getting each item correct.

Looking first at the difficulty of the items, we added these two results together and divided by two to get an estimate of the percent of the people taking the test who answered the item correctly. (This in turn yields an estimate of an infinite population of similar people who would answer the item correctly.) In Fig. 1, the results of this part of our analysis are shown. The easiest item turned out to be Number 10, with 84 percent of the 200 getting it correct. This was the item on the use of MIL-STD-105A. In fact, four of the five questions on single, double or sequential sampling plans were among the seven easiest. The hardest item was Number 25, which tested for knowledge of Tchebycheff's inequality (see Grant, pages 75-6). Despite the fact that most of the delegates to the convention answerd "c", 99.7% of all numbers will be within ± 3 σ *only* if the distribution is normal.

The general picture of item difficulty clearly shows that we met our goal of choosing items that ranged from very easy to quite difficult in approximately equal increments. (It also shows how poorly we succeeded in our effort to group the items roughly in their order of difficulty.)

The most useful measure of an item's worth is its ability to select superior from inferior ability. If the score on the whole test is taken as a criterion of superior or inferior knowledge of quality control, the discriminating power of any item is measured by the correlation between the score on the given item alone and the score on the entire test. Since we measured the percent of the upper and lower group getting each item correct, we use the tetrachoric coefficient of correlation for this double dichotomy. Its value can be estimated quite accurately and conveniently from Figure 21, Page 184 in Adkins "Construction & Uses of Achievement Tests" (US Civil Service Commission, Washington, D.C., 1947). In Fig. 2 the items are arranged vertically in the order of their power to discriminate. Note that the most discriminating items seem to be those involving simple definitions or names of men active in quality control. But isn't this natural? Those who know quality control will know the answers to such questions and those who don't know quality control probably won't.

Item 22 was the least discriminating of the 30 items ($r = 0.14$). It was intended to test for knowledge of the fact that a complete two component analysis of variance provides the same sort of information as X and R charts, since a test for homogeneity of variance is similar in purpose to an R chart and both an "F" test and an X chart compare within sample variations with between sample variations.

The low value of "r" for this item and the comments on some of the papers at the Convention point clearly to the fact that we did not construct a good item to test for this knowledge.

The general picture of the discriminating power of the items is encouraging, however, since in general practice, questions with an "r" of less than + 0.15 (including all questions with negative "r") are considered to have unsatisfactory discriminating power. According to this criterion only question 22 is unsatisfactory.

In addition to item analysis, another way to examine the worth of a test is to determine what is known as test reliability. This basically measures the degree to which an individual score is independent of chance fluctuation, and is reported as a correlation coefficient between two forms of the same test or two successive administrations of the same test. Inasmuch as this test was given but once and no other forms are available, direct calculations of the reliability is impossible. Fortunately, it can be determined from the difficulties, or percentages correct of the items, the item test correlations, and the standard deviation of the test, using the Kuder-Richardson formula (well-known to test makers). For our sample of 200 the test reliability was 0.87. As for all correlation coefficients, zero represents no correlation and unity represents perfect correlation. Thus 0.87 is a gratifingly high reliability for a 30-item test.

From the reliability and the standard deviation of the test scores we can determine the standard error of an individual's test score. For our data the standard error of a score is 2 points. This means that you will be correct 95% of the time in stating that your true score as measured by this test can be considered to be within ± 4 points of your actual score. For example if your score was 12, your true score as obtained from taking similar tests infinitely many times is quite probably between 8 and 16.

So you see there is inevitably an error in educational measurements, as in all measurements, and perhaps even though your actual score showed only average ability your true score would indicate good ability.

With the help of our test analysis, we could now construct a better test—but until we gave it to another large group of qualified subjects, we would have no norms. And the analysis clearly indicates that the test, in its present form, yields a reasonably good guide to one's knowledge of quality control. We hope that the items you missed will stimulate you to explore this fascinating field still further, thus accomplishing the test's real purpose—to present a useful learning experience.

Figure 1—Graph of Item Difficulties
(Based on random sample of 200)

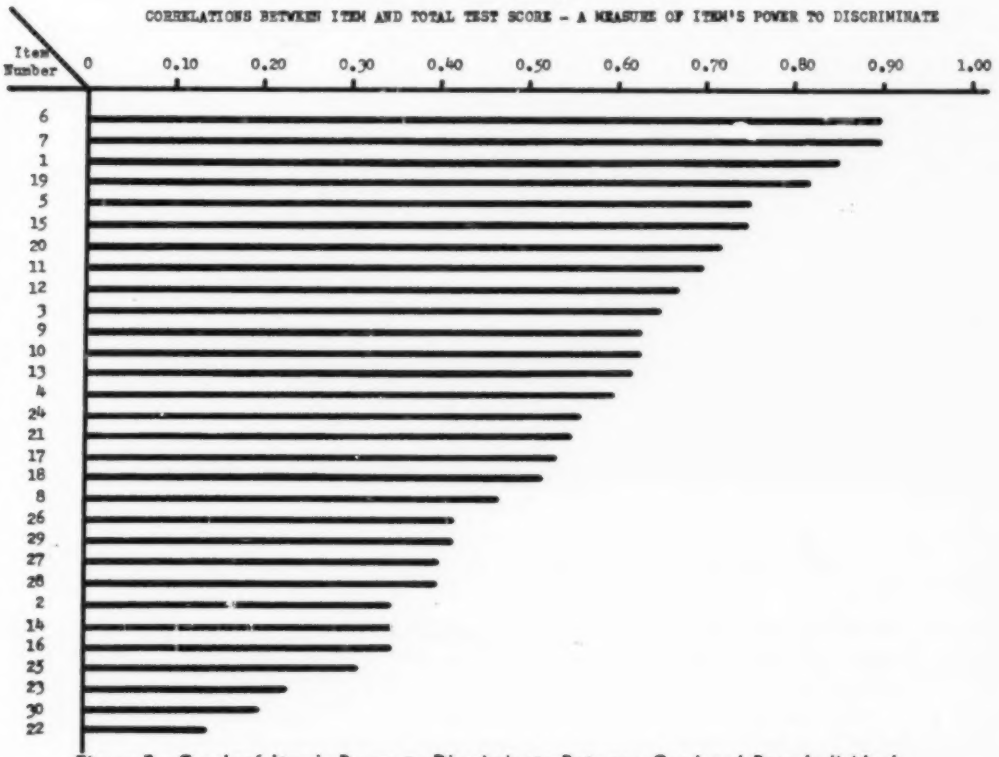
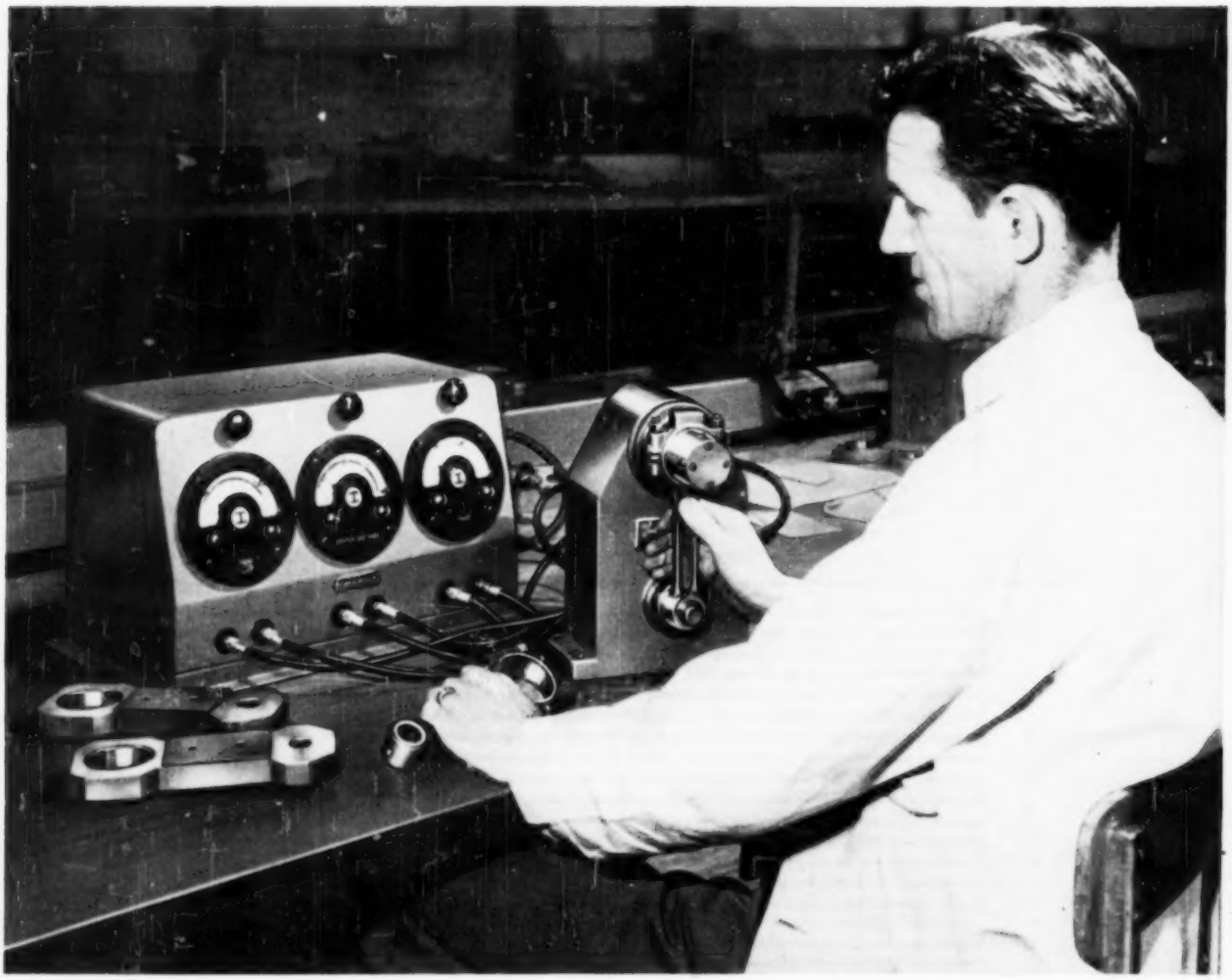


Figure 2—Graph of Item's Power to Discriminate Between Good and Poor Individuals
(Based on random sample of 200)

Only a Taft-Peirce *Offers these 4*



1 Computes Difficult Measurements Automatically

A T-P Computing CompAIRator eliminates the need for two measurements and a calculation. One gage, one dial, measures, calculates and indicates the final answer instantly on the dial face, for such difficult measurements as center distance without respect to hole size, deviation from angle or taper, concentricity, and squareness of bore to face.

The three dial Computing CompAIRator pictured above does the work of six dials in checking bend, twist, and center distance of connecting rods.

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CompAIRator Air Gage
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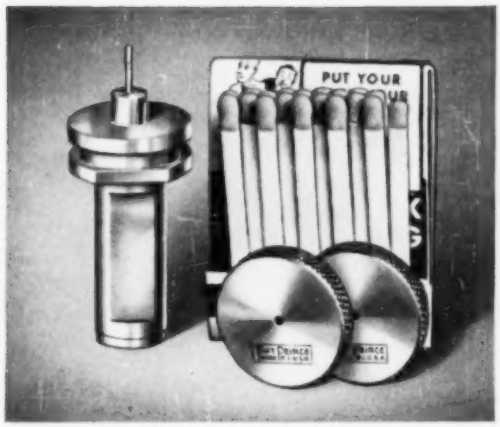
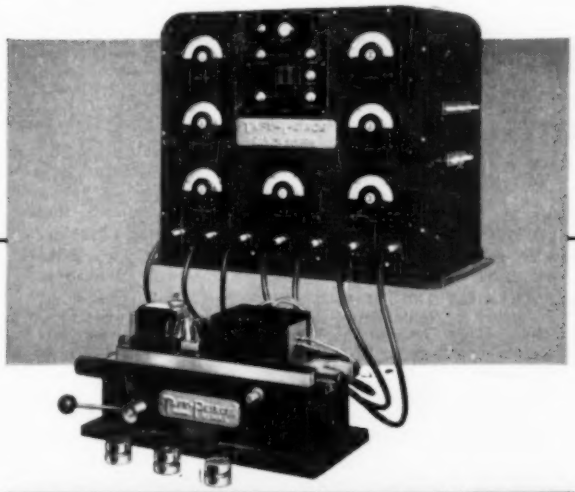


2 Checks Diameters as small as .055″

The velocity-type circuit of a T-P CompAIRator, which permits use of tiny air passages and nozzles, makes these small measurements possible quickly and accurately.

3 Checks Tolerances up to 120 thousandths

T-P CompAIRator air-contact members can be furnished to permit measurements within this wider tolerance range with a standard unit.



4 Gives Simultaneous Signal Light and Dial Indications

A T-P Air-Electric CompAIRator offers the ultimate in speed for multi-dimensional gaging. It provides both exact size on standard dials *and* light indications for oversize, undersize, and within tolerance conditions.

Couple these great features with the greater speed, accuracy, and dependability of a T-P CompAIRator — and you know why thousands use and prefer them. Write for demonstration at your plant. Prove the time and money saving differences for yourself.

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COMPANY, WOONSOCKET, RHODE ISLAND

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New Taft-Peirce GRANITE SURFACE PLATE Keeps Measurements On The Level

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ACCURATELY GROUND AND LAPPED, backed by more than 75 years of experience in making precision products, Taft-Peirce Granite Surface Plates are the newest addition to a famous line of layout and inspection equipment.

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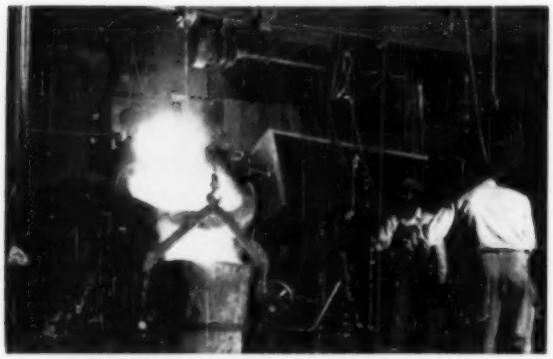

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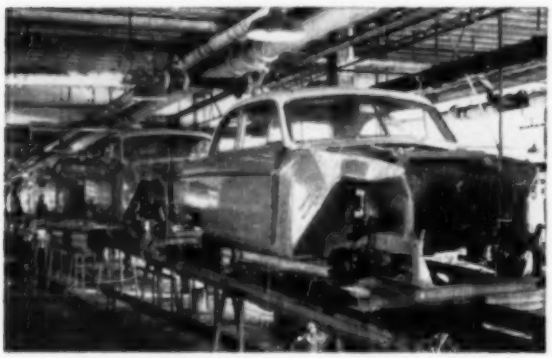

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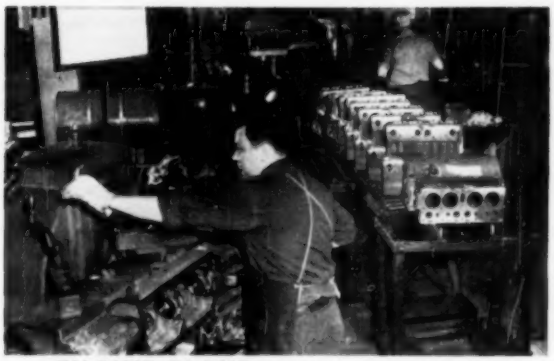

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Which Sampling Plan Should I Choose?

DR. JOHN W. ENELL
New York University

Modern developments in sampling theory have permitted us to construct sampling plans whose behaviors are rather exactly predicted. Nowadays we have available extensive published lists of sampling plans: the Dodge-Romig tables, MIL-STD-105A, and many more which are in less wide use. Indeed, the industrious quality control engineer can construct a special plan suited to any clearly stated need. Tell him what are good and bad levels of quality, what risks you are willing to tolerate, and he will be able to set up precise instructions for the inspector.

Old-time rough rules, such as "inspect ten percent of each lot and reject the lot if any defectives are found," were generally used without knowledge of the risks being taken and without realization that the extent of protection depended on the size of the shipment. It is easy to avoid errors of this kind today. You do not have to be a mathematician. All that is necessary is to select your sampling plan from a recognized table of plans.

THE PROBLEM

Nevertheless there is still a puzzling problem: Which plan fits my needs? The tables list hundreds of sampling plans. Which acceptable quality level (AQL) or average outgoing quality limit (AOQL) or lot tolerance percent defective (p_t) is appropriate for a particular product? Honesty compels me to report that the choice of risks and percentages just referred to is still largely by rule of thumb in industry today.

In fact I had one client who was using clandestine photostats of a competitor's sampling plans. Each sheet was labeled with a percentage. Unfortunately he had never been able to find out how these percentages were defined — whether they were quality averages, minimums, maximums, or what.

A sampling plan, no matter how scientifically designed, is only as solid as our knowledge of the protection we need. In consequence, it cannot yet be said that the use of sampling has become 100 percent scientific. Guesswork too often enters into our specification of the quality level required.

Properly used, the sampling plan is a sensitive device. We are wasting some of its abilities when we fail to define our requirements for protection exactly. It is rather like using a fine lathe and a supermicrometer to obtain a diameter which the designer has specified only to the nearest 1/16th inch.

In this paper I would like to consider one practical approach to the problem of determining the requirements for a sampling plan. I will deal chiefly with the choice of AQL's for MIL-STD-105A since this is probably the most widely used table of attribute sampling plans at present. In this way I can be more specific.

When your product is bought by the armed forces, they will normally specify the acceptable quality level, at least for the finished product. In effect they will choose the sampling plan for you, if one is to be used. (All you have to worry about is how to attain the required quality!) I do not know whether their methods for selecting AQL's are more scientific than yours or mine, but in any event the decision is out of our jurisdiction.

The problem *is* ours, however, for most commercial products. Here we must decide for ourselves what quality level is necessary. And even where the end product is for the armed forces, we will generally be responsible for proposing suitable sampling for receiving inspection and for process control.

TO SORT OR NOT TO SORT?

To start with, let me ask why we sample. In acceptance sampling (to which this discussion is limited) the object is to decide on disposition of the lot. The alternatives are to accept or reject the lot which is before us.

A suitable sampling plan should reject when rejection is cheaper, and accept when acceptance is cheaper. It is as simple as that.

A lot which is accepted may (according to the laws of probability) have some defectives in it. When the decision is to accept, we should consider the costs these defectives generate: extra labor, materials, or overhead expenses incurred by letting some imperfect parts go on through production. Sometimes it involves very little effort or expense to set aside in the shop parts with minor defects.

A lot which is rejected will normally be sorted. If this is the case, and defectives found are repaired or replaced, the total of these costs is the price of rejection.

Let's look at an example. Consider the case of punched pieces of mica film used in certain condensers. Pinholes or conducting inclusions are fatal defects. They short circuit the finished unit. The total cost of manufacture is lost since it is impracticable to salvage any part of the unit, which is molded in plastic.

Costs and definitions of symbols are as follows:

A = Unit cost of acceptance (harm done when a defective piece slips through into subsequent production operations) = 10.5 cents

I = Cost of inspecting one piece (good or bad) = 0.1 cent

C = Cost of repairing or replacing a defective component once found = 0.5 cent

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p = the (unknown) fraction defective in the lot

R = Unit cost of rejection (cost of finding a defective in a rejected lot, plus expense of correcting it) = C + I/p

All this will be clearer if we draw a picture (see Fig. 1). The straight horizontal line at 10.5 represents the loss we suffer whenever a defective piece of mica is used and results in a scrapped condenser. This line goes straight across the diagram because the cost of each scrapped condenser is the same regardless of the number produced.

The curve represents the cost of finding and replacing a defective mica film as a result of sorting after the sampling plan has rejected the lot. Suppose two percent of the pieces of mica in the lot happen to be defective. Then on the average the inspector will find one bad piece in each 50 he tests. The cost of finding this bad piece will have been

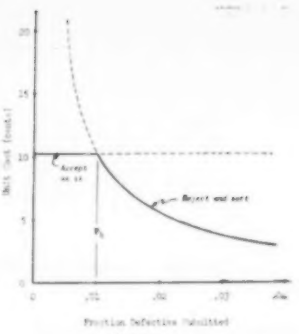


Figure 1

I/p = I x 50 = 0.1 x 50 = 5 cents. The value of the defective film is 0.5 cent. The total cost to find and replace it is therefore 5.5 cents if there are two percent defectives. Other points on the curve are found similarly.

One can see from examining the completed chart that the curve (cost of rejecting, sorting, etc.) is lower than the straight line (cost of accepting) if the incoming percentage defective is greater than one percent. Thus a suitable sampling plan should usually reject in this region.

The reverse is true if the percentage defective is less than one percent. Then it is cheaper to accept without further ado.

At one percent, the breakeven point, the loss is the same whether we accept or reject. Evidently the two line cross when

$$A = R = \frac{I}{p} + C$$

That is, $p_b = I/(A - C)$. The ratio of these costs is all that matters, not the absolute values. In everyday usage we do not need to draw the chart at all; we merely note the ratio.

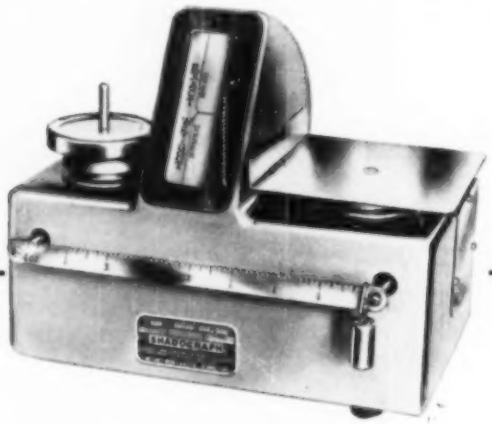
If the cost C to replace the component part is small compared to A, the damage done by a defective which slips through, then the relation is approximately

$$p_b = \frac{I}{A} = \frac{\text{Cost to Inspect One Piece}}{\text{Damage Done by One Defective}}$$

If the component parts are sold to us by another company, and the cost of replacement is not borne by us, this is an exact ratio.

WHICH AQL TO USE

To make our economics usable we must translate our breakeven data into an AQL or other sampling plan designation.



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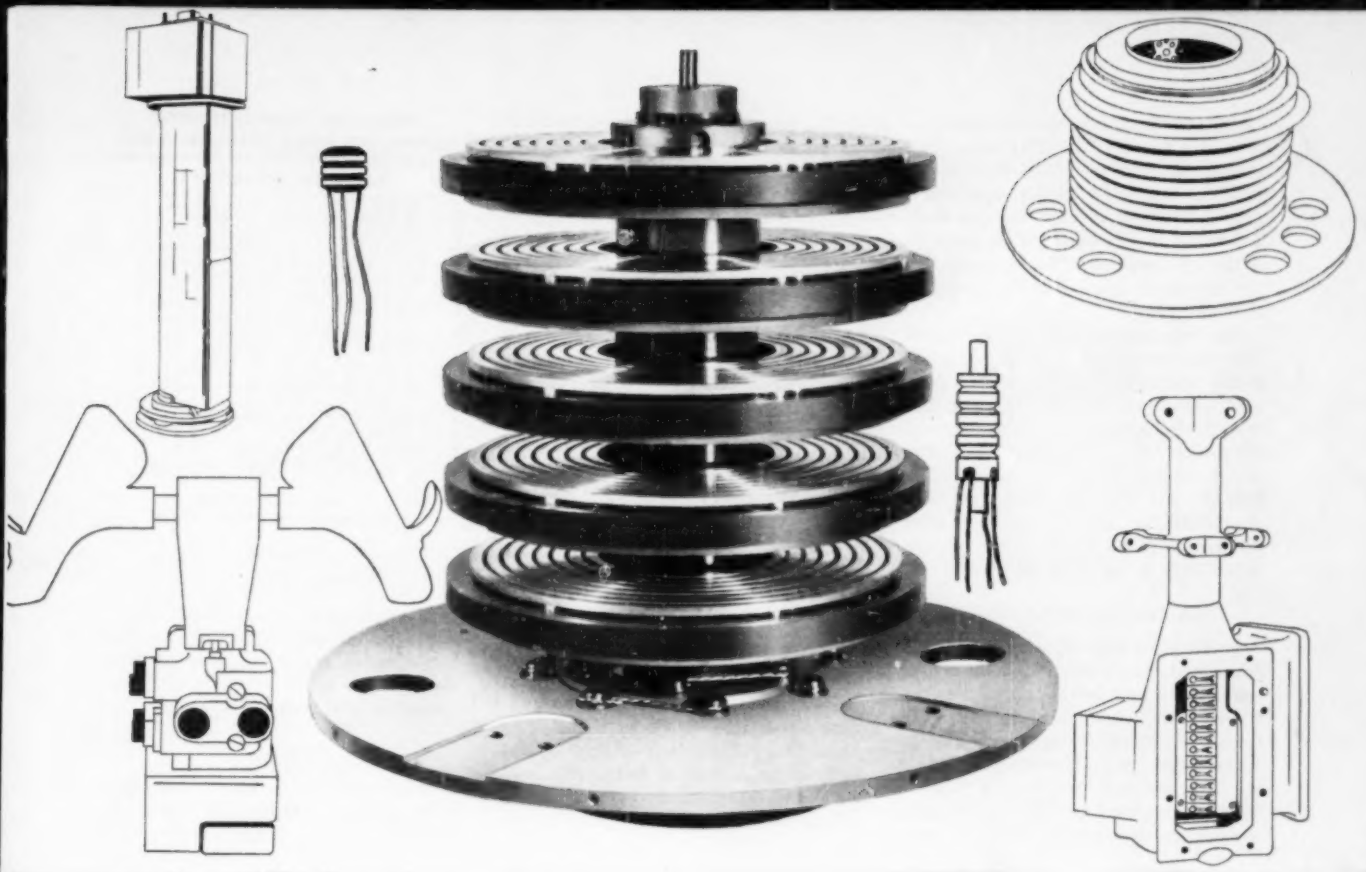

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Suppose the mica usually comes to us in shipments of 15,000 pieces. For normal inspection MIL-STD-105A provides that letter N sampling plans should be used for lots of this size. Referring to Figure 2 (from page 45 of the military standard) we see the characteristic curves of a number of these plans.

Our economic analysis indicated that the sampling plan should generally accept lots less than one percent defective and should generally reject lots more than one percent defective. This implies a curve which passes near the probability 0.50 at one percent defective. The characteristic curve for the plan labeled AQL = 0.15% is nearest to this. This is the plan to adopt.

PRACTICAL PROCEDURE

It should not be inferred from the foregoing that charts must be drawn and curves consulted by the inspector every time a sampling plan is to be used. Once it has been recognized that the dominant factor is p_b, it is possible to set up a tabulation recommending AQL's appropriate to various ratios. This is used by the persons charged with setting up plans, *not* the inspector at the bench.

Such a tabulation is shown in Chart 1.

AQL's are often set by a committee consisting of representatives of quality control, engineering, and sometimes production or others. In going over various dimensions and other quality characteristics this committee should strive to estimate the ratio of unit inspection cost to damage done by one defective. The tabulation can then be used to translate this ratio into an AQL.

The AQL's listed in Chart 1 are for the MIL-STD-105A plans nearest to 0.50 probability at the breakeven point. Persons who prefer to err on the side of overinspection may wish to use the next smaller AQL.

At final inspection, customer safety, good will, and other intangibles are involved. These being difficult to evaluate in dollars, I can only suggest that a tightened AQL be used. Any such plan of action really amounts to placing some dollar equivalent on the intangibles even when we declare ourselves unable to measure one.

WHEN NOT TO SAMPLE AT ALL

As previously indicated, a prime purpose of acceptance sampling plans is to determine whether it is cheaper to endure the costs of acceptance "as is" or to search out and correct the defects. (There may of course be other subsidiary objects such as the rating of quality of outgoing product.)

The sampling inspection itself costs money. Past records or other evidence may sometimes indicate that quality is quite usually well to one side of the breakeven point. Where this is the case the sampling plan will habitually make the same decision. Then you may well say, "Why not skip the sampling? Let's just omit inspection altogether, or use 100 percent inspection, as the case may be."

The crucial factor in deciding whether to use sampling in such instances is not so much the *average* percent defective as the variability from lot to lot.

If the quality is substantially better than breakeven, and stable as well, no inspection may be needed. If it is substantially worse than breakeven, and consistently so, it will be cheapest to use 100 percent inspection without stopping to sample. If the quality is erratic, then sampling will pay for itself.

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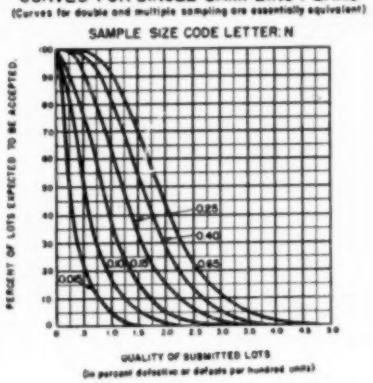


Figure 2

CLOSURE

It is my hope that you will agree that we should make less use of the crystal ball in fixing AQL's and other standards of perfection. The method we have discussed has the advantage of being simple while keeping our eyes on the main factors that should affect the decision. I think an answer based even on rough economics, is a move in the right direction. Undoubtedly we will think of refinements as we go along.

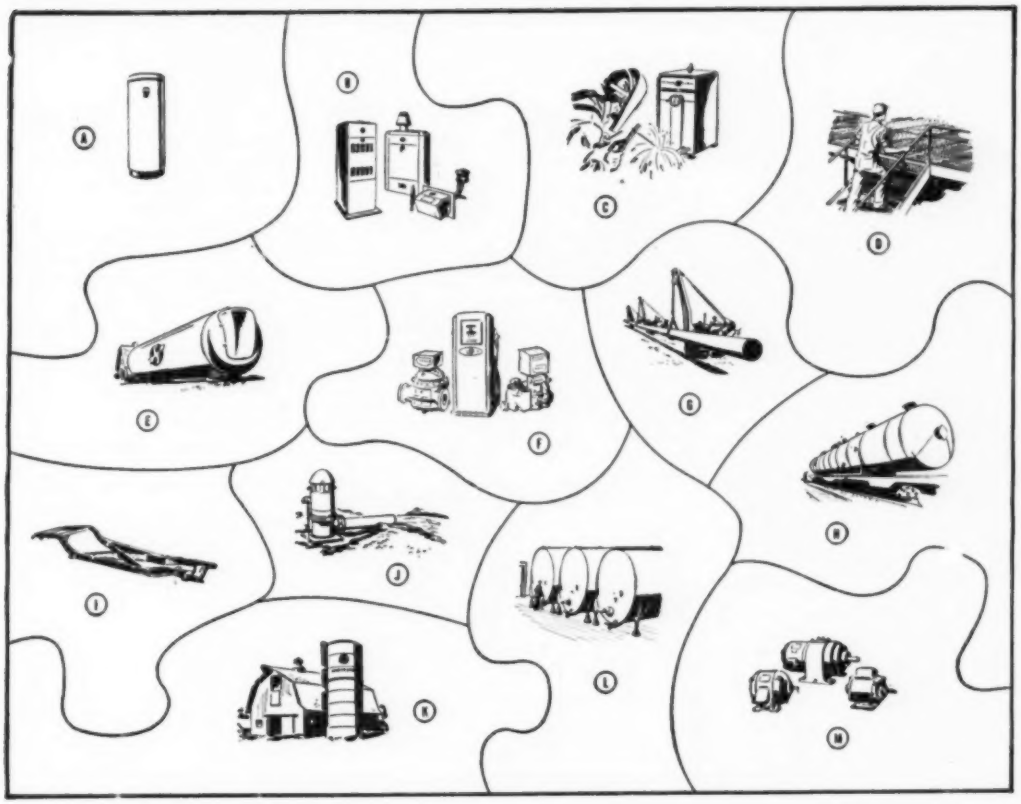
REFERENCE

Quality Control Handbook, J. M. Juran, McGraw Hill, 1951, section 7, "Statistical Methods in the Quality Function" by J. W. Enell, pp. 413-15.

CHART 1—AQL's Suggested for Various Ratios of Unit Inspection Cost to Unit Damage

for p_b of . . .	use AQL of . . .
1:900	0.015
1:400	0.035
1:300	0.065
1:200	0.10
1:150	0.15
1:90	0.25
1:65	0.40
1:50	0.40-.65*
1:33	.65-1*
1:25	1-1.5*
1:20	1.5-2.5*
1:12	2.5-4*
1:9	4-6.5*

*The smaller (tighter) AQL should be used where normal lot sizes are less than 1000.



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The principal feature of the machine is its combination of all essential gear checks. A table motion parallel to the axis of the gear checks the lead. A perpendicular motion checks involute or tooth profile, and the in-and-out motion of the indicator slide checks the spacing. Complete information on the Analytical Comparator is available on request from **Illinois Tool Works**, 2501 N. Keeler Avenue, Chicago 39, Ill.

• • •

The Hanson-Whitney Internal Thread Comparator, just introduced, is designed for fast, accurate and economical variable gaging of all

forms and classes of internal threads, in diameters ranging from $\frac{3}{8}$ to $1\frac{1}{2}$ in. The indicator tells at a glance whether parts are oversize, undersize, tapered, or if accumulated lead and angle error are within established tolerances. All classes of fit, American Standard or Unified Threads can be checked with a simple adjustment of the indicator tolerance hands. One thread segment is collapsible, permitting fast loading. Ball bearing, single slide design insures accuracy over a long service life. Easily removable thread segments permit interchangeability and fast setup. Information may be obtained from **Hanson-Whitney Company**, 169 Bartholomew Ave., Hartford 2, Conn.

• • •

A complete line of optical tooling and gaging is being imported by

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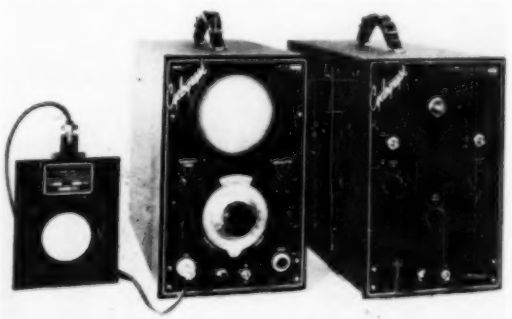

The CYCLOGRAPH (Model C)

This instrument permits truly high speed, non-destructive sorting of raw, semi-finished or finished parts by their metallurgical characteristics. With the new Automatic Sorter Unit speeds up to 300 pieces per minute are possible with the use of suitable feeding equipment. Used by leading industrial firms everywhere.

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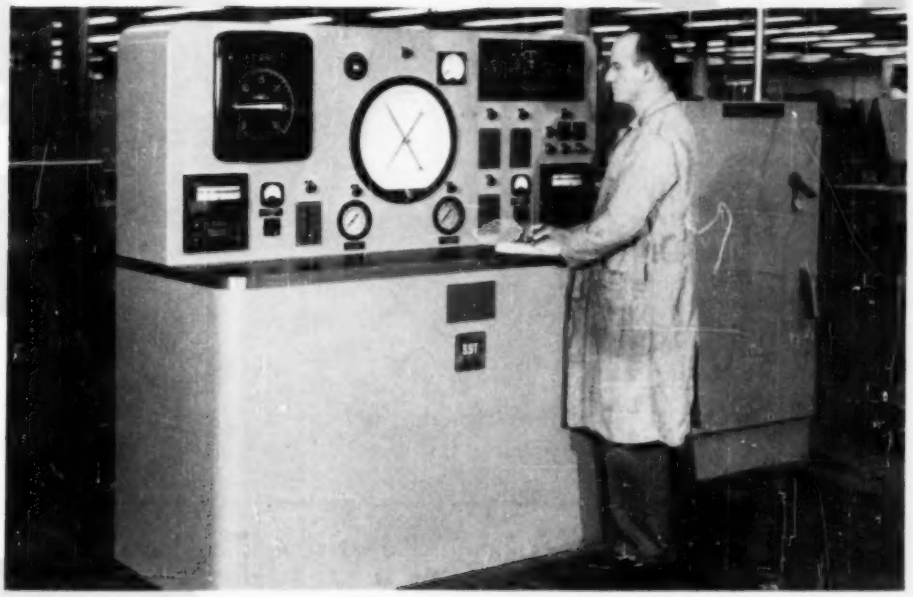


International Harvester continually strives toward improving the quality of its products. Above, the control panel of the "Fatigue Testing Equipment," developed by IH engineers for testing heavy duty gears to destruction, registers the effects of increased loads upon these gears.

What does increased engine horsepower require of heavy duty gears? How do increased loads on transmission gears affect materials, heat treatments and lubricating oils? International Harvester engineers find out . . . by testing heavy duty transmission gears *all the way to destruction!*

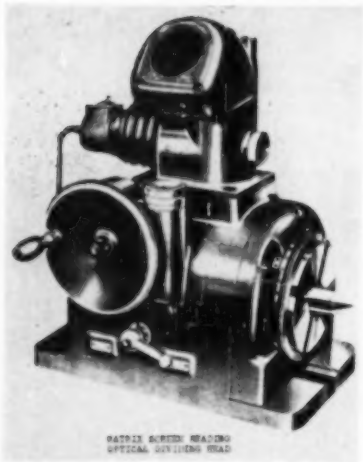
The capacity of ordinary gear dynamometers did not permit such research. IH metallurgical and design engineers, working with equipment manufacturers, directed the development of "Fatigue Testing Equipment." This machine, two years in the making, has sufficient capacity to test heavy duty gears—under simulated field conditions—to death.

Controlling quality by destroying gears is part of Harvester's extensive research and testing program found in all divisions. We believe that constant, active control of quality leads to customer satisfaction . . . farmers with Farmall Tractors, housewives with International Harvester refrigerators or freezers, construction engineers with IH power units, truck-line operators with International Trucks, home owners with the new Harvester air conditioners.

From heavy duty transmission gears in a tractor to the push-button automatic defroster of a refrigerator . . . every piece of International Harvester equipment is quality controlled to do the best possible job.

INTERNATIONAL HARVESTER

The confidence in IH products comes from the quality built into them



Engis Equipment Company, Chicago. Typical of this equipment is the new Matrix Screen Reading Dividing Head. This unit reads directly on a shielded screen to 12 seconds of arc, with convenient estimation to 3 seconds. Operation is extremely fast, and head may be used for production in grinding and milling, as well as for inspection.

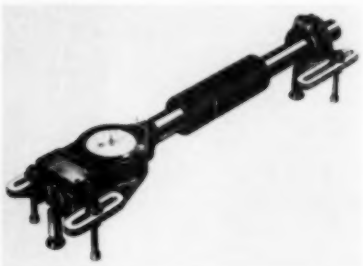
* * *

The new Leitz Micro-Hardness Tester has just been placed on the market by the **George Scherr Company,** 200 Lafayette Street, New York 12, N. Y. It is a portable bench type instrument combining a positive controlled diamond penetrating action with a high power microscope of 400 magnifications. The microscope is swung directly over the impression to read the hardness by measuring with a reticule scale and vernier in .0005 millimeter, resulting in hardness readings of unusual precision in half a micron. Instructions and table are furnished with the instrument converting readings into Rockwell and other standard hardness scales.

The instrument is well-suited for small or highly finished parts, since impressions caused by the diamond cannot be seen with the naked eye and are so small that even the finest finish is not marred by the test. Coarse impressions such as Brinnel ball test may be measured with the coordinate measuring stage, such as is found on toolmakers' microscopes, thus making the tool more useful for general optical measuring of any kind.

* * *

A new Universal I.D.-O.D. gage, designed especially for gaging shallow bores and shoulder diameters, is now being manufactured by **Federal Products Corporation** of Providence, R. I. This gage features adjustment to suit diameter require-



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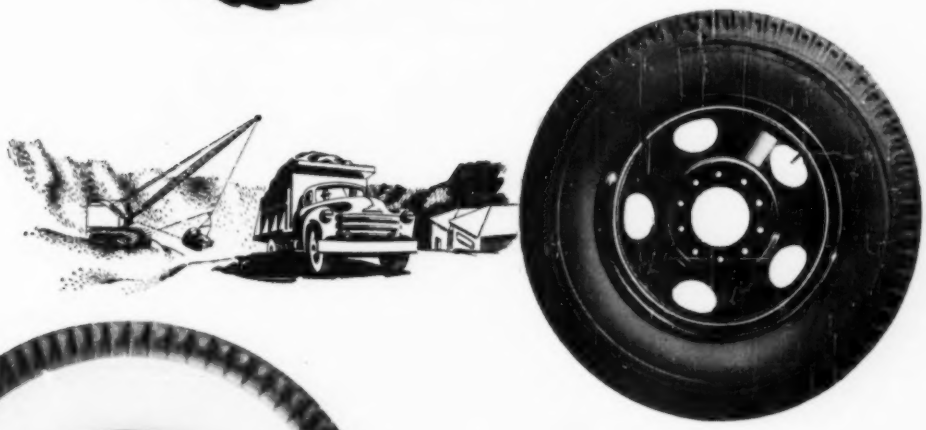

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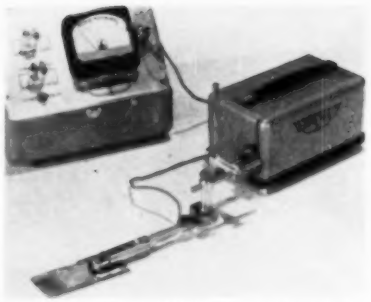
ments and locating buttons which can be adjusted for height to locate the measuring contacts at the desired elevation. It has a tubular frame equipped with one or two insulated hand grips, depending on the length of the tube. Measurement is transferred from the measuring contacts to the dial indicator through a sensitive pantograph unit. Gages can be made up from stock parts in lengths varying from six to 42 in., in three-inch increments. Although each gage is furnished for a specific diameter measurement at a specific depth, certain adjustments are possible. Vertical adjustments can be made for depths up to one inch and the reference contact can be moved along the length of the tube to measure smaller diameters than specified.

* * *

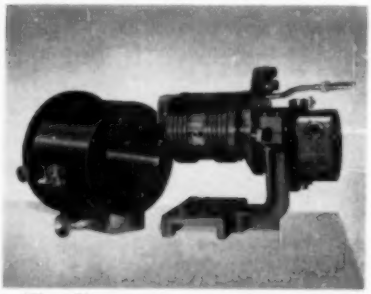
There is now available a mechanical tracing accessory for use with the Brush Electronics Company's Surfindicator. The Motor Drive, Model BL-114, provides mechanical movement of the Surfindicator pick-up along a surface being inspected. It is designed to extend the usefulness of the basic Surfindicator beyond the range that is practical with



hand operation. It has a reciprocating stroke adjustable from 2⅞ in. to less than 1/16 in. with a stroke speed of ⅛ in. per second. The Motor Drive is especially recommended where highest possible accuracy, large quantity inspection of similar parts, very fine finishes and very small areas are involved. For further information, write to **Brush Electronics Company**, Equipment Division SP, 3405 Perkins Avenue, Cleveland 14, Ohio.

* * *

Central Research Laboratories, Inc., Red Wing, Minn., announce the development of the Model HC-101 High Temperature X-ray Diffraction Powder Camera for general purpose investigations of substances at controlled elevated temperatures up to 1000 degrees centigrade. The camera has a movable film carrier that allows five 7-mm diffraction patterns to be made on the same film, facilitating the determination of phase diagrams and registering comparison patterns or different substances at selected temperatures.



The film carrier may be removed from the furnace assembly at any stage of the investigation without disturbing the thermal environment of the powder sample. Coiled helix furnace heating elements are of platinum-rhodium, supported by two concave ceramic bodies, separated by 3-mm spacing which allows the diffraction to pass to the film. Radiation and convection losses are minimized and the temperature of the specimen can be changed from one thermal level to another with equilibrium being obtained rapidly. Several accessories for controlling power input and measuring temperature are available.

* * *

Sigmatic automatic inspection machines are high-speed 100% sorting machines which can do simultaneous inspection of ten dimensions, or less, on parts up to 1 x 1 x 2 in. The machine illustrated is tooled up to inspect accounting machine type for length, width, thickness, straightness — a total of six dimensions. Within 20 min., this tooling can be removed and replaced by other tooling for inspection of internal or external dimensions of different parts. During inspection each dimension is checked by a Sigma Microlimit gage, accurate to within .00005 in., and adjustable for various tolerances. Speed, when parts are fed into the machine from hand loaded magazines is 2300 per hour, and when hopper fed, 3600 per hour. Inspected parts are automatically sorted into oversize, undersize and acceptable, then dropped into separate drawers at the side of the machine. Built-in counters tabulate the number of parts submitted for inspection and

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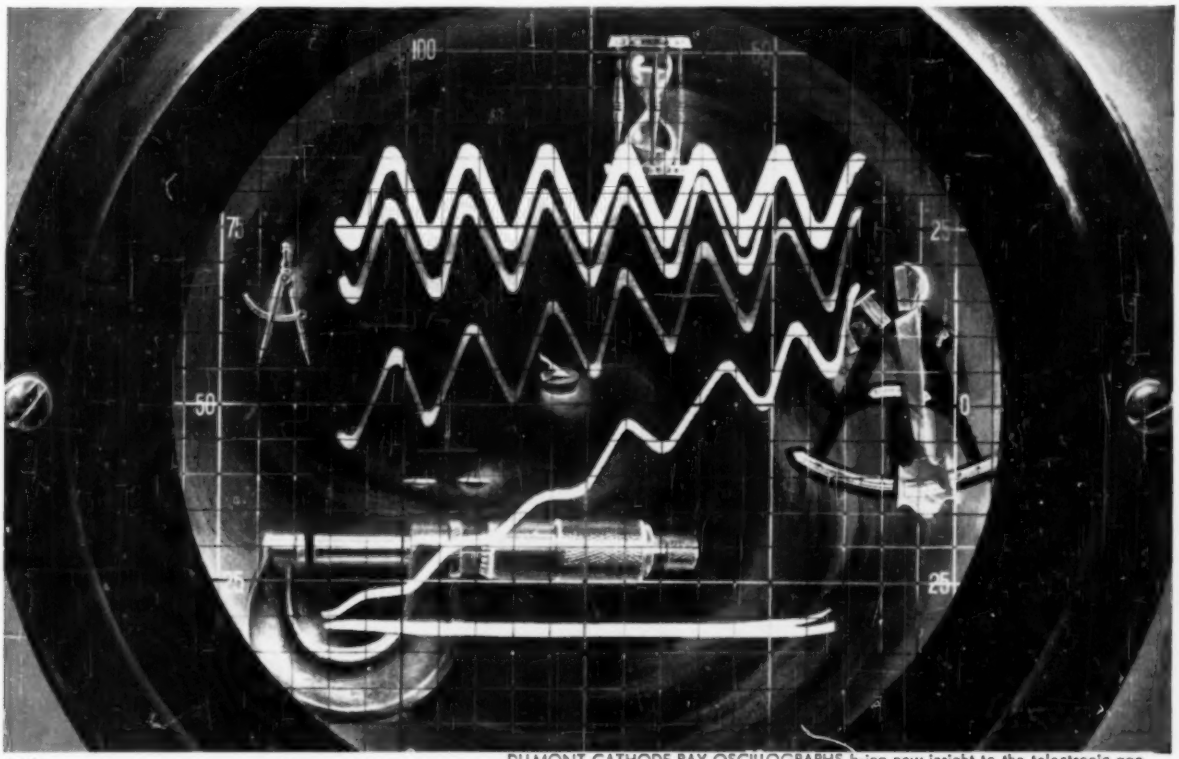
Today this Du Mont cathode-ray oscillograph is essential to accurate automatic mass-production control. It is one of the most highly valued tools of nuclear research, medicine, acoustics, metallurgy, chemistry, automotive and aircraft engineering.



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Now Du Mont is the world's foremost manufacturer of cathode-ray oscillographs, and Du Mont oscillographs are the accepted *standard* of accuracy and dependability. Like so many Du Mont achievements in other fields of telectronics . . . television receivers, tubes, transmitting and studio equipment and government projects . . . Du Mont instruments are designed to lead the way. They are working now to make today's visions tomorrow's realities.

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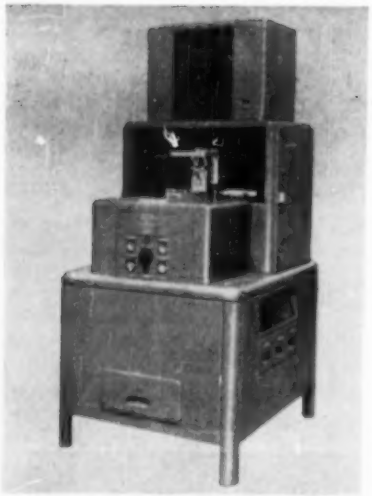


the number accepted. Sigmatic machines are manufactured by the Sigma Instrument Company of Letchworth, England, and the sales representative in the U. S. is the **Cosa Corporation**, 405 Lexington Avenue, New York 17, N. Y.

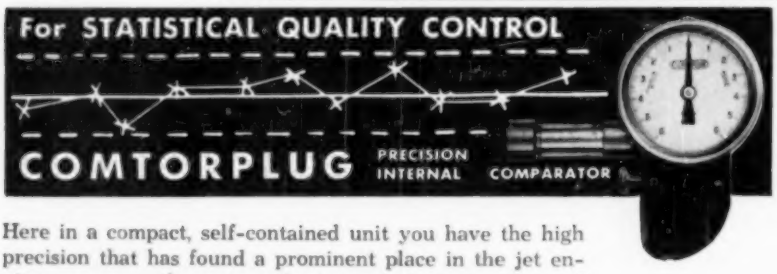
* * *

An improved taper thread gage, adopted by the U. S. Army Engineers to check all compressed gas valves and cylinders procured for government use, was shown to the annual meeting of the Compressed Gas Association in New York. The new gages are used to assure leakproof fits on all NGT (National Gas Taper) threads on valve to cylinder connections. In design they are similar to conventional rings and plugs for taper pipe threads, but have an added helical scale, or ramps, with numerical values for easy and definite reading. These gages were designed by Myron E. Steczynski, advertising manager of the Bastian-Blessing Company, Chicago, and a consulting engineer for the Compressed Gas Association. Gages are manufactured by **The Sheffield Corporation**, Dayton 1, Ohio.

* * *

A new type of eyeglass loupe which may be used interchangeably on either metal or plastic spectacle frames is being manufactured by the **Bausch and Lomb Optical Company**, Rochester, N. Y. Designed for industrial use by toolmakers, inspectors, and workers on fine assembly and wiring operations, as well as

watchmakers, the loupe is available with either single or double lenses. Single lens models are available in 3X, 3.3X, 4X, 5X and 7X. The double lens model provides magnifications of 4X or 7X, depending on whether one or both lenses are used. A two-way clamp accommodates either a thin metal or a thicker plastic spectacle bow. Prices are $3.25 for the single lens model and $5.25 for the double lens.



Here in a compact, self-contained unit you have the high precision that has found a prominent place in the jet engine program, the automatic transmission program and other fast moving set-ups. Used at machine or bench, Comtorplug has self-aligning features assuring accuracy. Ideal for Statistical Quality Control programs. Comtor Co., 80 Farwell St., Waltham 54, Mass.

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Yesterday, samples were drawn and tested again. Today, with final approval given, the barrel rolled under the bung hammer.

This long-term screening and testing is part of the network of quality controls which guards Schenley whiskies. Guards their goodness from the time the grain is grown till the whiskey is in your glass . . . and brings you the utmost enjoyment in every drop of every drink.

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ANALYSIS OF VARIANCE

FACTORIAL DESIGN IN THE STUDY OF CHEMICAL REACTIONS, Herbert Grohskopf, American Cyanamid Co., New York, N. Y.
(Ind. and Eng. Chem.—v. 45, n. 3, June 1953, p. 1260)

Discusses general principles of the application of factorial design and analysis of variance to pilot plant scale studies. Examples are given illustrating the analysis of a three-factor experiment each at two levels. Discussion and examples limited to Model I experiments.

Describes organization of factorial experiments including balancing and replication of factors and randomization of variables incident to the design. This is followed by an example which describes the process, measurements, and design as well as discussion of the significant factors and interactions and their meaning. Details and given of the variance analysis including source and pooling of error estimates, tests of significance and interpretation of confidence limits.

APPLICATION—CHEMICAL INDUSTRY

FILTERABILITY OF CELLULOSE ACETATE SOLUTIONS, Lionel A. Cox, American Viscose Corp. Marcus Hook, Pa. and William K. Mohney, American Viscose Corp., Meadville, Pa.
(Ind. and Eng. Chem.—v. 45, n. 8, Aug. 1953, p. 1798.)

Precision of the filtration method is established by calculation of standard deviations of filtration constants over selected ranges of filtration pressures.

APPLICATION—METALLURGICAL INDUSTRY

STATISTICAL QUALITY CONTROL IN SMALL-LOT HEAVY MANUFACTURING, Leo W. Bosch, Imperial Works, United States Steel Corporation.
(Factory v. 111, n. 11, Nov. 1953, p. 98)

This article discusses the application of statistical quality control at the Imperial Works of the United States Steel Corp.

This article points out the necessity of developing specific approaches for the particular problems of a given operation. The solution of this problem and the advantages gained in this one company are discussed.

STATISTICAL QUALITY CONTROL, A. J. Kukla, Chemical Laboratory Supervisor, Buffalo Works, Aluminum Co. of America.
(Foundry—v. 81, n. 12, Dec. 1953, p. 120)

This article deals with application of statistical quality control to a magnesium sand foundry. The program consists largely of using X and R charts to publicize scrap and promote friendly rivalry between shifts and between individuals. In this industry, the variability in individuals is often more important than the variability in machines.

APPLICATION—METAL WORKING

STATISTICAL QUALITY CONTROL IMPROVES EFFICIENCY OF CHROMIUM PLATING OPERATION, Frank L. Bonem, International Harvester Co., Evansville, Ind.
(Products Finishing—v. 17, n. 11, Aug. 1953, p. 24)

Illustrates uses of statistical methods in control of plating of parts used for agricultural implements. Details of the process and examples of control charts given. The pinpointing of reject causes is stressed.

APPLICATION—MISCELLANEOUS

SOME APPLICATIONS OF STATISTICAL QUALITY CONTROL IN THE PAPER BOXBOARD INDUSTRY, Brainard E. Sooy, Chief of Quality Control, Gardner Board & Carton Co.
(Paper Trade Journal—v. 136, n. 26, June 26, 1953, p. 20)

Mr. Sooy describes many of the general considerations and some of the specific details of applying statistical quality control at the Gardner Board and Carton Co. In introducing this paper, Mr. Sooy points out the necessity for each industry developing its own

ACKNOWLEDGMENTS

Several references in this bibliography have been supplied by the International Statistical Institute, *International Journal of Abstracts on Statistical Methods in Industry*, Grant I. Butterbaugh, International Editor, Charles A. Bicking, American Editor.

The chemical division, ASQC, and the statistical committee, TAPPI, are also contributors.

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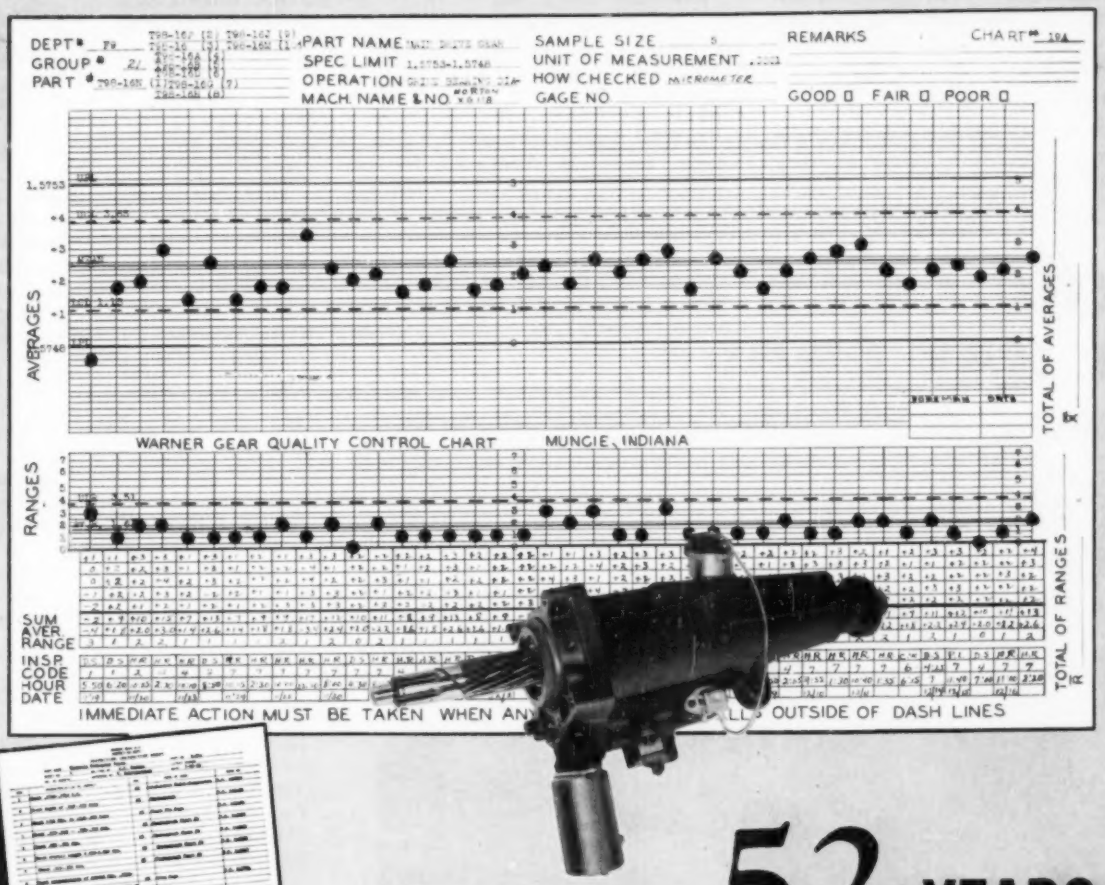

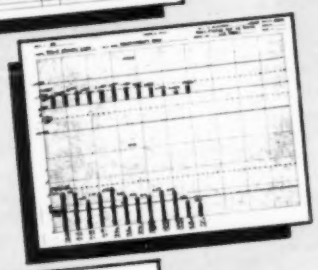

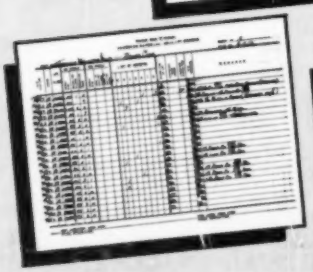

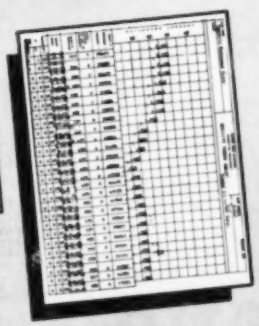

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applications from basic fundamentals. The success of statistical quality control at the Gardner Co. is indicated.

CONTROL CHARTS

PROCESS ANALYSIS BY CONTROL CHARTS, Martin H. Saltz, Quality Control Engineer, Hughes Aircraft Co., Culver City, Calif.
(The Tool Engineer—v. XXXII, n. 3, Mar. 1954, p. 66)

This article describes the basic concept of the average and range chart and its application. Numerous diagrams illustrate the distribution concept upon which the average and range chart is based. The relationship between processes, tolerances and print specifications is also discussed and illustrated.

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Hour after hour of high capacity baling is the key to New Holland's popularity among farmers who bale hay. This Model 66 Baler is designed particularly for the family-size farm. Top performance in a baler is especially important because the quality of the hay drops steadily after the right time for harvesting.

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New Holland, through its quality control program, builds machinery a farmer can depend on in the crucial times in his harvesting season. A pioneer in automatic balers, New Holland believes quality control plays a big part in backing up its slogan of "First in Grassland Farming".

New Holland Machine Company, a subsidiary of The Sperry Corporation, New Holland, Pennsylvania.

NEW HOLLAND
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ENGINEERING AND EXPERIMENTS

ANALYSIS AND CORRELATION OF TEST DATA, Irving W. Burr, Professor of Mathematics, Purdue University.
(Metal Progress, v. 64, n. 4, Oct. 1953, p. 112)

In this article, Mr. Burr discusses in some detail the theory and application of statistical methods to the broad problems of analysis of basic test data. Concepts of random sampling, frequency distributions, population versus sample, and effective sample size are discussed. Specific techniques of analysis include analysis of variance and the correlation scatter diagram. The selection of sampling plans is also outlined. This article is highlighted by questions asked by the audience when the paper was first presented as part of an educational series. These questions and answers tend to supplement the paper and point out details of application.

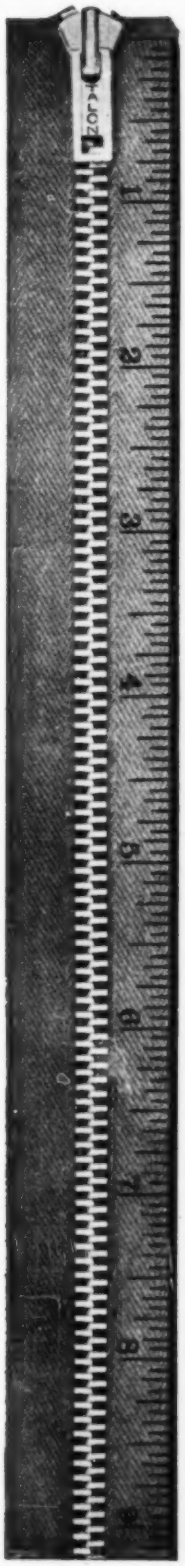
TEN PRACTICAL USES OF STATISTICAL QUALITY CONTROL IN METALLURGICAL PLANTS, John W. Hood, Head, Quality Standards Department, Metallurgical Division, Aluminum Co. of America.
(Metal Progress—v. 64, n. 5, Nov. 1953, p. 82)

Mr. Hood describes uses of statistical quality control at Aluminum Company of America's operations. These include:

I Quality Assurance
II Operator Interest
III Basis for Decisions
IV Incentive to Earn Low Inspection Costs
V Customer Quality Standards
VI Compliance with Government Inspection Standards
VII Establishing Tolerance—Machines and Methods
VIII Control of Laboratory Methods
IX Planning Technical Experiments
X Aid in Labor Relations

SOME APPLICATIONS OF STATISTICAL ANALYSIS IN THE STEEL INDUSTRY, J. W. W. Sullivan, Metallurgical Engineer, American Iron and Steel Institute.
(Metal Progress—v. 64, Dec. 1953, p. 91)

all the others are measured



by this one

Inside and outside the zipper business, there's one unchanging standard of perfection recognized by everybody. And that's the Talon zipper . . . designed and engineered to a quality so high that *any* zipper's worth can only be determined by comparison with this one.

Talon

THE QUALITY ZIPPER

TALON, INC., MEADVILLE, PA.
IN MEXICO, CIERRE RELAMPAGO
IN CANADA,
LIGHTNING FASTENER CO., LTD.

This article discusses the application of statistical analysis to variability in the steel industry. A detailed discussion of three applications includes control charts for coating on galvanized wire; the testing of rust preventive oil; and the determination of hardenability bands.

(The three articles in the October, November, and December "Metal Progress" are from a related series of discussions. The first of this series was reported in a previous bibliography, and was from the September issue of "Metal Progress.")

MANAGEMENT AND PERSONNEL, GENERAL

EYE CAMERA SHOWS HOW TO IMPROVE INSPECTION TECHNIQUES, (Factory—v. 111, n. 12, Dec. 1953, p. 88)

An interesting study of the use of the "Eye" camera on a problem of visual inspection. Not statistical quality control.

REDUCED INSPECTION PROVES QUALITY, G. H. Prudden

(American Machinist, v. 97, n. 26, Dec. 7, 1953, p. 125)

Savings gained by putting production departments on their mettle for quality. Not statistical quality control.

MISCELLANEOUS

ORDNANCE RELIABILITY THROUGH QUALITY CONTROL, Major General Leslie E. Simon, Assistant Chief of Ordnance, Washington, D. C.

(Ordnance—v. 38, July-August 1953, p. 56)

The parallel growth of statistical quality control and of the complexity of military equipment are compared. Although it was not until the Korean War that quality control was extended successfully to a whole ammunition system, Ordnance is now embarked on the far more complex task of applying this scientific discipline to improving the reliability of complex systems like guided missiles.

An organization that has been set up to correlate this activity is described. The plans depend on team work between Ordnance and science and industry.

QUALITY CONTROL AND INSPECTION, W. L. Young, Timken Roller Bearing Co.

(Instruments—v. 26, Dec. 1953, p. 1884)

Article describes methods of manufacturing and controlling quality of roller bearings. Lists sequence of operations and location of inspection to insure control. Cites improvement in rejects and quality due to program. Not statistical quality control.

SAMPLING PLANS AND RELATED TOPICS

NOMOGRAPH FOR EVALUATING THE SIGNIFICANCE OF SOME TEST RESULTS, Chou Hsiung Li, RCA, Harrison, N. J.

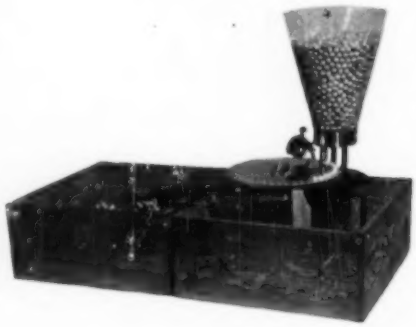
(A.S.T.M., Bulletin—n. 194, Dec. 1953, p. 74)

Article gives nomograph for quickly evaluating the significance of differences of number of defectives found in samples of equal size. Statistical background and examples of use detailed.

APPROXIMATING THE MODE FROM WEIGHTED SAMPLE

QUALITY CONTROL DEMONSTRATORS

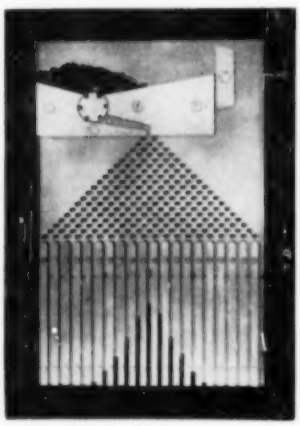
Demonstrate the Fundamentals of Quality Control Without the Use of Mathematics



Show the efficiency of 100% inspection with this motorized demonstrator—defective balls lettered K-H-S-Y — 3000 7/16" diameter plastic balls furnished—complete with carrying case 14" x 13" x 11"—110 volt ac.

Show the effectiveness of $\bar{X}$, R or $\bar{X}$, σ control charts with this portable quincunx quality control chart demonstrator—made of aluminum finished in gold and black—weight 11 lbs. —11" x 14" x 1"

Other demonstrators—assembly tolerance, sampling, etc.—can be made if volume warrants.



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Whether it be a carton of toothpicks or a battery of kitchen ranges—a case of toilet tissue or a dish washer, no matter what you buy here, it is guaranteed! Back of our *written* guarantee on EVERY ITEM is the name and reputation of DON. And in addition to QUALITY, VALUE, CHOICE and positive SATISFACTION, you get the service you're entitled to! Each order is shipped quickly—*usually the very same day it is received!*

A few of the 50,000 items sold by DON and listed below may suggest something you need NOW!

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- Silverware
- Trays and Covers
- Towels (Paper-Cloth)
- Electric Vegetable Peelers
- Floor Matting
- Sinks (Stainless Steel —Galvanized)
- Double Boilers
- Chinaware
- Tables and Chairs
- Floor Maintenance Machines
- Ovens (Gas-Electric)
- Towel Dispensers
- Ash Trays and Stands
- Mixers (All Kinds)
- Polishes and Cleaners
- Bar Stools
- Menu Covers
- Pots and Pans
- Lamps
- Bed Linens
- Dish Washers
- French Fry Cutters
- Utility Carts
- Cutlery
- Deodorizers
- Guest Room Furniture
- Toasters
- Spreads and Blankets
- Water Pitchers
- Mops and Brushes
- Ice Chippers
- Plastic Tableware
- Roll and Food Warmers
- Water Coolers
- Bar Supplies
- Steam Tables
- Soaps and Detergents
- Table Linens and Napkins
- Can Openers
- Vacuum Cleaners
- Uniforms
- Hospital Supplies
- Butter Cutters
- Electric Clocks
- Ranges and Broilers
- Glassware
- Paper Cups and Straws
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VALUES, Howard L. Jones, Illinois Bell Telephone Company, Chicago, Ill.
(Journ. Am. Stat. Assoc.—v. 48, Mar. 1953, p. 113)

The weighted mean of ordered sample observations can be used to approximate the mode under favorable conditions, where the weights are determined from the first two terms in a Taylor expansion of the maximum likelihood estimate. Such weights are shown in Table 1 for the case where the sample is selected from a t-distribution with known kurtosis.

DESIGNING SINGLE-SAMPLING INSPECTION PLANS WHEN THE SAMPLE SIZE IS FIXED, Abraham Golub, Ballistic Research Laboratories, Aberdeen Proving Ground)
(Journ. Am. Stat. Assoc.—v. 48, June 1953, p. 278)

A simple technique is developed for determining "best" single-sampling inspection plans when the sample size is fixed. Two cases are considered: (1) single-sampling plans for placing a lot into one of two categories and (2) single-sampling plans for placing a lot into one of three categories. For case (1), the "best" plans are based upon a criterion of minimizing the sums of the producer's and consumer's risks. A similar criterion is employed as basis for choosing "best" plans for case (2). The more general result for m categories is given also. Tables 1 through 8 are presented to enable the user to choose the appropriate sampling plans.

CONFIDENCE INTERVALS FOR THE NUMBER SHOWING A CERTAIN CHARACTERISTIC IN A POPULATION WHEN SAMPLING IS WITHOUT REPLACEMENT, Leo Katz, Michigan State College, Lansing, Mich.
(Journ. Am. Stat. Assoc.—v. 48, June 1953, p. 256)

In a number of different sampling situations, we encounter a problem which may be stated as follows: From a population of N objects, each of which possesses or does not possess a certain characteristic, we select without replacement a random sample of n objects. Observing that m of these possess the characteristic in question, we wish to estimate the total number M having the property. In this paper, the problem is considered and two approximate methods are given for construction of these confidence intervals.

THE UP-AND-DOWN METHOD WITH SMALL SAMPLES, K. A. Brownlee, J. L. Hodges, Jr. and Murray Rosenblatt, University of Chicago.
(Journ. of the Am. Stat. Assoc.—v. 48, June 1953, p 262)

The up-and-down method for estimating the 50-percent response point of quantal data was originally devised for testing the sensitivity of explosives. The main content of this paper is a report on computations made to determine the actual performance of some estimates for the mean dosage parameter based on up-and-down series of length ten or less.

THEORY AND APPLICATION—GENERAL

QUALITY CONTROL THROUGH STATISTICAL METHODS: V CONTROL

WIRE and CABLE made BETTER

by Quality Control

There are just 3 reasons why more and more people specify Rockbestos Wire and Cable every day:

Each Rockbestos item is *designed* to give maximum safety and service on the job.

Each is skillfully *made* to these specifications with the right materials . . .

And *held* to closer quality tolerances than ever before by Statistical Quality Control. At Rockbestos, the exact, unerring yardstick of statistics gages every step of manufacture from incoming raw materials to the outgoing finished product.

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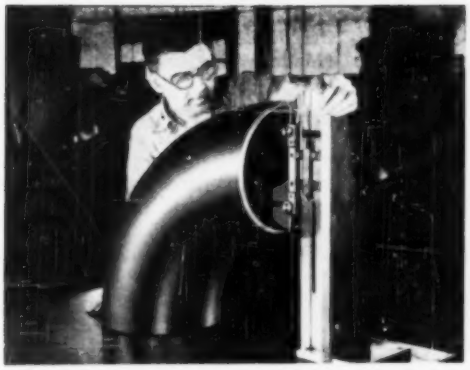
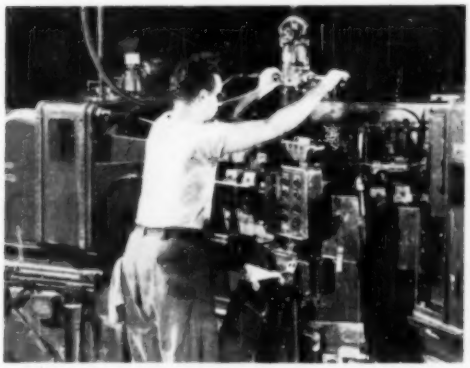
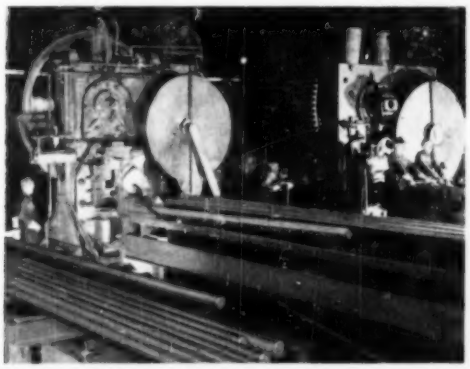


Statistical methods in physical inspection of Ladish fittings improve uniformity of the products.



Applying quality control principles to machining assures predictably closer tolerance work.



Greater efficiency in cutting mults to length is achieved through statistical quality control.

Forging operations controlled by statistical methods result in more uniform physical dimensions.

HOW STATISTICAL QUALITY CONTROL METHODS ASSIST IN GIVING LADISH

Controlled Quality

FITTINGS AND FORGINGS INCREASED RELIABILITY

Illustrated at left are typical inspection and production operations in the Ladish plant which have been made more efficient by the application of statistical quality control.

This statistical method of quality control is incorporated into the Ladish Controlled Quality program wherever it demonstrates an ability to maintain existing standards effectively or indicates an opportunity of raising the over-all quality of operations to higher planes. It functions as one of the vital tools which build maximum reliability and dependable performance into every Ladish Controlled Quality fitting and forging.

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Small Hole Gauge No. 36

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The Ames No. 36 has extremely sensitive mechanism especially designed to eliminate "feel" in measuring. The spherical contact point automatically centers itself and indicates the true diameter at the point measured. The operator has only to slide the contact in and around the hole and note the readings to determine if tolerances are being met.

The Ames Small Hole Gauge No. 36, using contacts in increments of 1/32", can check holes of 3/16" to 1" diameter, up to 2" depth. Longer lengths and special contacts to check irregular recesses, splines, etc., can be supplied.

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Mfgr. of Micrometer Dial Gauges • Micrometer Dial Indicators

CHARTS, Norbert Lloyd Enrick
(Modern Textiles—v. 35, n. 2, Feb. 1954, p. 35)

Control charts are described and explained in some detail. The use of the average chart, average and range chart, and process average, is explained and illustrated. Interesting illustrations of problems in the textile industry and hints for the use of these methods are given.

(Parts I through IV are reported in previous bibliography sections.)

STATISTICS

FITTING OF THE POSITIVE BINOMIAL DISTRIBUTION WHEN BOTH PARAMETERS ARE ESTIMATED FROM THE SAMPLE, F. E. Binet
(Annals of Eugenics—v. 18, Sept. 1953, p. 117)

NOTE ON DODGE'S CONTINUOUS INSPECTION PLAN, G. J. Lieberman
(Annals of Math. Stat.—v. 24, Sept. 1953, p. 480)

SOME TESTS BASED ON ORDERED OBSERVATIONS FROM TWO EXPONENTIAL POPULATIONS, B. Epstein and C. K. Tsao
(Annals of Math. Stat.—v. 24, Sept. 1953, p. 458)

ON THE POWER OF A ONE-SIDED TEST OF FIT FOR CONTINUOUS PROBABILITY FUNCTIONS, Z. W. Birnbaum
(Annals of Math. Stat.—v. 24, Sept. 1953, p. 484)

QUALITY × QUANTITY INTERACTION, A. A. Rayner
(Biometrics—v. 9, Sept. 1953, p. 387)

ON SOME PROCEDURES FOR THE REJECTION OF SUSPECTED DATA, E. P. King
(Journ. Am. Stat. Assoc.—v. 48, n. 263, Sept. 1953, p. 531)

DISTRIBUTION OF THE PRODUCT OF RANGES IN SAMPLES FROM A RECTANGULAR POPULATION, P. R. Rider
(Journ. Am. Stat. Assoc.—v. 48, Sept. 1953, p. 546)

CONFIDENCE AND TOLERANCE INTERVALS FOR THE NORMAL DISTRIBUTION, F. Proschan
(Journ. Am. Stat. Assoc.—v. 48, Sept. 1953, p. 550)

INDUSTRIAL QUALITY CONTROL

Local Section News

". . . BUT NOT FORGOTTEN"

BUFFALO Leon Bass, General Electric Co., addressed the Mar. 29 meeting of this section on the subject "Statistics in Electronics."

BUZZARDS BAY Two color-sound films on production methods and quality control techniques were shown at the Mar. 11 meeting of the Buzzards Bay section. The films were made by the Acushnet Process Co. and the Revere Copper and Brass Co. in New Bedford.

The section is sponsoring two consecutive courses on quality control which began Mar. 18. Each course consists of five weekly sessions of two hours each; the first is devoted to control charts, and the second to acceptance sampling. The instructor is Paul Krensky, assistant chief QC engineer, Gillette Safety Razor Co., Boston.

CHICAGO The final meeting of the Chicago section was held on Mar. 24 at the Furniture Mart on the ever important subject "Quality Control Training." The meeting consisted of a panel of three experienced SQC'rs: Henry Becker, Robert Lace, and Richard Ede with moderator Dr. Marge Sutherland. The meeting was conducted as a question and answer session with each of the panelists expressing his opinion on each question. Just before dinner, Nicholas Relich gave a talk on "SQC Concepts in Layman's Language." The entire session was a fitting climax for the year's excellent program.

CLEVELAND On Apr. 2 the Cleveland section held its regular monthly meeting at the Cleveland Engineering Society Building. E. L. Fay, Deere and Company, spoke on the topic "How Quality Control Helps Supervision." Many people in supervisory positions attended this discussion. In addition Miss Bertha Wellman, Industrial Editor of the *Cleveland Press* attended the meeting as a guest of the section.

On Mar. 15 there was an Executive Committee meeting of the Cleveland section during which plans were prepared for the filming of our recent successful television presentation on quality control.

It was further agreed to present a spring educational program in the form of a six weeks' short course. These sessions were started on Apr. 21 and are being conducted by Dr. Fred Leone of Case Institute of Technology.

DALLAS-FT. WORTH At the March meeting of this section E. L. Fay, Deere & Company, spoke on the subject "Using the Tools of Quality Control."

On Apr. 8 Capt. B. L. Lubelsky, USN, commander of McAlester Ordnance Depot, spoke on the subject "Application of Machine Control Chart Theories."

DAYTON J. M. Juran, management consultant, spoke at the Apr. 7 meeting of this section on the subject "What Is the Quality Control Job?"

DELAWARE At the April meeting, Jim Mitchell, superintendent of development and control, Tennessee Eastman Co., discussed the prime importance of accuracy and precision in chemical analyses in the chemical industry in his talk "Control of the Accuracy and Precision of Industrial Tests and Analyses."

ERIE On Mar. 3 Prof. Ralph Swalm of the Smith College of Engineering at Syracuse University introduced us to "Ratio Delay Techniques." In spite of the worst blizzard of the season our members from 40-mile-distant Meadville and Corry, Pa. were out in full strength.

INDIANAPOLIS Members of the Indianapolis section spent a very instructive and pleasant evening on Mar. 16 when E. E. Schiesel, Mattatuck Mfg. Co., gave his talk on "Quality Control Techniques in Tooling and Methods Improvement." The talk gave a different approach on quality control techniques to the members of the section.

At the 4:30 session C. R. Hicks, assistant professor of mathematics, Purdue University, gave a chalk talk entitled "Some Quick and Dirty Statistical Methods."

INDIANAPOLIS
Lafayette Subsection The first regularly scheduled meeting of the newly formed Lafayette subsection was held on Mar. 26, at Purdue University. R. S. Saddoris, A. O. Smith Corp., gave a very interesting talk to the 119 people who were in attendance for the meeting. We feel that this very rousing attendance for the initial meeting of the new subsection is a good omen.

LINCOLN On Friday, Apr. 9 in the Zephyr Room of the Capitol Hotel the members of the Lincoln section heard Herschel R. Harrison discuss the various applications of quality control at Collins Radio Co.

LOS ANGELES
San Bernardino Subsection On Mar. 2 Carl Boswell gave an interesting and informative talk on "How to Sell Quality Control." He pointed out the new approaches and new techniques, such as "Work Sampling" and "Ratio Delay," that are now gaining the ear of management.

Paul F. Paskert, Hughes Aircraft, spoke on "Realistic Tolerances Through Quality Control" at the Apr. 1 meeting.

The subsection voted unanimously to separate from the Los Angeles section and to seek full section status

as of July 1. Advanced dues for 1954-55 covering approximately 35 members will be forwarded with the request. The new section will be known as the San Bernardino section.

MICHIGAN On the night of Mar. 19, in spite of the adverse weather conditions, a good turnout of "Michigan Faithfuls" journeyed to Ann Arbor, to hear Dorian Shainin, Rath & Strong, Inc., present his very interesting paper on "Determining Practical Tolerances." The advance publicity appealing to engineers brought forth many guests who were thoroughly enlightened by Dorian's explanation of why "two and two do not always make four."

MINNESOTA Leo Harrington, King-Seeley Corp., was the featured speaker at the Mar. 5 meeting and his address, "Sequential Analysis" attracted a crowd of 50. Mr. Harrington covered some of the applications of this technique to inspection at King-Seeley as well as some important work in statistical determination of tolerances.

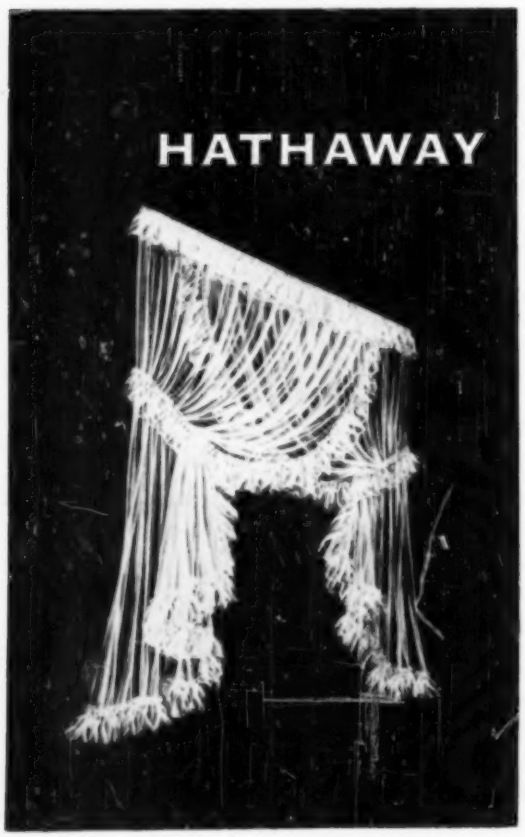
MUNCIE Apr. 6 saw this section engage in a special project which was one of the highlights of this year's activities. Individual members of the Northeastern Indiana and Indianapolis sections, together with members of the Muncie Foreman's Club were invited to join us in hearing Dr. J. M. Juran discuss, "What Is the Quality Control Job?" We were happy to be able to present Dr. Juran with such a fine turnout, and happy to present such a large audience with such a fine speaker.

NEW HAVEN On Mar. 11, we were fortunate in having as our guest speaker, William A. MacCrehan, Bendix Radio. Mr. MacCrehan's topic "The Tower of Babble" was well presented and thoroughly enjoyed by the good attendance. Another feature of the evening was a one act play by Leonard Seder, presented by the "Thespians" of the local section.

NORTHEASTERN INDIANA Capt. Henry Simon, Headquarters AMC, Wright-Patterson AFB, delivered a film-illustrated talk on Mar. 11 to the Northeastern Indiana section. Subject of Capt. Simon's presentation was "A Comprehensive View of Air Force Quality Control." Capt. Simon outlined briefly the history of the Air Force quality control development and in particular the post war II development. He discussed at length what the quality control program means to the Air Force and what is expected of it. The meeting was followed by an informal social get-together.

PHILADELPHIA Our March meeting, held on Thursday the 18th, presented C. A. Bicking, Army Ordnance Research and Development Division. Mr. Bicking discussed the "Technical Aspects of Quality Control."

Don Best, our Problem Clinics Chairman, lead the clinic sessions, which are now being held at 6:30 p.m. instead of 4:30 p.m., as in the past.



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From the very moment the bright Du Pont nylon yarn enters the mill . . . through twisting, conditioning, warping, winding, slashing, weaving, inspection—all operations are carried out under the most modern quality-control methods. This kind of quality control all along the production line, makes Hathaway Balanced Nylon an outstanding example of manufacturing skill and precision for product perfection.

HATHAWAY MANUFACTURING CO.
New Bedford, Massachusetts
LEADING WEAVERS OF FINE FABRICS SINCE 1888

RACINE At the regular meeting on Apr. 1, the nomination for 1954-55 officers was held, a slate of officers suggested by the nominating committee being accepted. A letter ballot will go out to the membership.

A. E. Jakel presented a short but very informative talk "Object of Process Quality Control" further illustrated by two films on quality control and acceptance sampling.

RHODE ISLAND Paul C. Clifford, New Jersey State Teachers College, highlighted the Mar. 18 meeting with a discussion of "Some Basic Concepts of Quality Control."

ST. LOUIS Our March meeting was naturally the largest one attended so far this year. Approximately 80 persons, or about one-half of our membership, attended the plant tour of Cook's Imperial American Champagnes and Wines. After a most enlightening discourse, as we traveled through the cellars and hallways, we were brought back to the reception room where champagne truly flowed.

SEATTLE On Mar. 9 E. T. Dalton, Pictsweet Foods, spoke on "Quality Control in Processing Frozen Fruits and Vegetables." Mr. Dalton showed how a modern quality control program using statistical methods can efficiently develop information on processes and products and how such increased operational knowledge can contribute to improved economy and product quality. Attention was called to the frozen food processors' particular problems in the practice of quality control principles.

The Second Pacific Northwest Quality Control Conference, presented by this section and the University of Washington, was held at the University campus on Apr. 2 and 3. The Conference Committee, with Dr. G. I. Butterbaugh as coordinator, assembled an excellent program studded with outstanding quality control leaders and featured as speaker at the luncheon Miner Baker of the Seattle First National Bank. The conference was well attended by enthusiasts from many businesses of manufacture and service.

SOUTHERN CONNECTICUT J. Philip Worth, Electrolux Corp., Old Greenwich, Conn., gave an interesting discussion—"Who Controls the Vendor's Quality," at the Mar. 10 meeting in the Stratfield Hotel, Bridgeport.

TENNESSEE This section is pleased to announce that its members in the Memphis area have recently organized the Memphis subsection, the first subsection to be recognized by the Tennessee section.

The section is also pleased to report that the membership in the Chattanooga area is currently going through the throes of organization and it is expected that recognition will soon be granted to this subsection.

TENNESSEE Memphis Subsection Wendell H. Abbott, General Electric Co., Cleveland, spoke at the February meeting on

More and Finer Products at LOWER UNIT COSTS!

HOW TO INSTITUTE QUALITY CONTROL AS AN OPERATING PROCEDURE—using

R. G. Bock P. Q. Scopes with the Quality Index of Standard Conformity.

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A completely NEW Outline of Practice available to Quality Control and Operating Executives upon request . . . address

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(Our organization also renders a consulting Service to Industry in instituting Statistical Methods of Quality Control.)

"Statistical Applications in Everyday Manufacturing Problems."

WESTERN MASSACHUSETTS The Mar. 9 meeting was attended by 24 members and 54 guests who heard Adam Abruzzi, Stevens Institute of Technology, speak on "Quality in Work Measurement." Mr. Abruzzi directed a good part of his talk to the many time study and methods people that were our guests. His emphasis was that time study problems should be approached very much in the same manner that problems are approached by people in statistical quality control. His feelings were that time study should be made on a random basis both as to time and individual study. The plan he suggested was akin to that of "Ratio Delay Studies."

WICHITA The year 1954 was ushered in with a most interesting meeting and dinner for the Wichita section. ElCharro Dining Room was the setting for 84 members and guests. After dinner, program chairman Layton introduced the speaker of the evening, Capt. Wade S. Quick, Jr., Headquarters AMC, Wright-Patterson AFB. Captain Quick's subject was: "Consumer-Vendor Relationships and Air Force Quality Control Policy." Captain Quick covered his subject completely and in a most enjoyable manner. His handling of such timely topics as MIL-Q-5923B, GFE, Air Force future concepts of contracts, and communications problems was lengthy, but always sparkling with humor and sincerity.

The Feb. 2 dinner-meeting was held at Lydroy's Grill with 112 members and guests in attendance. Section chairman Forrest Calhoun introduced the featured speaker of the evening J. Y. McClure, of Consolidated Vultee Aircraft. Mr. McClure's address was divided into two parts, his main topic covering "Quality Control and Cost Reduction in the Airframe Industry." Mr. McClure made a few introductory remarks, then presented a running commentary to a series of slide pictures illustrating the organization, operation and results of their quality control program as designed to increase efficiency, improve quality and reduce production costs. The second portion of Mr. McClure's talk consisted of a twelve-point report from the November meeting of the Society's Board of Directors in Providence.

One hundred and three members and guests met at Lydroy's Gill for the Mar. 2 dinner-meeting. In the absence of the chairman, Ralph Humphries presided and introduced Mrs. Vida Grace Hildyard, secretary, who made announcements relative to the ASQC dance, eligibility for professional senior member grade and the Ninth Midwest Conference. Mr. Humphries introduced the program chairman, Bob Layton, who presented the subject for panel discussion as: "MIL-STD-105A, Classification of Defects, and Sampling Procedures." Mr. Layton made several comments regarding the topic for discussion and then introduced the panel—Moderator M. W. Compton, USAF, Wichita Regional Office; Max Eaton, Beech Aircraft Corp.; E. E. Rippey, Cessna Aircraft Co.; and R. E. Layton, O. A. Sutton Corp. The panel had received several written questions in advance that provoked lively discussion by the panel. Questions from the floor were numerous and were handled by the moderator and panel with dispatch and a knowledge of statistical quality control that made this meeting a highlight of the year.

UNIVERSITY OF WESTERN ONTARIO Dale L. Lobsinger, United Air Lines, gave a very interesting talk on "Some New Applications of QC" at the Mar. 12 dinner meeting held in the William Pitt Hotel in Chatham. J. B. Bassett conducted the afternoon educational session using "The Use of the Frequency Histogram as a QC Tool" as his theme.

A joint meeting with the Toronto Section was held on Mar. 17 in the cafeteria at Chockshutt Farm Equipment, Ltd., Brantford, Ont. A panel was made up of: D. A. Irwin, Canadian Arsenals, Ltd., R. J. D. Gillies, Case Institute of Technology, A. P. Deacon, Cockshutt Farm Equipment, Ltd., R. W. Glenfield, Dominion Tire Company, D. J. Malott, Essex Wire Corp., Ltd. with Prof. Brant Bonner, University of Western Ontario, as moderator, were present to answer the numerous questions presented.

At long last, on Mar. 24, 38 members and guests from

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the London area met at the Town and Country Club, St. Thomas, Ont., for a dinner meeting and conducted tour through the plant of the Timken Roller Bearing Co.

"... CAST THEIR SHADOWS BEFORE"

CLEVELAND Since the Mar. 5 meeting of Cleveland section was snowed out, the section has re-scheduled this meeting for May 21. Guy G. Parkin, Minnesota Mining and Manufacturing Co., will present a talk on the subject which he originally planned, "Significance Tests Applied to Industrial Processing."

DALLAS-FT. WORTH The final meeting of this section on June 10 will be a dinner meeting and installation of officers. Guest speaker will be A. C. Esenwein, vice-president and division manager of Convair, who will talk on the subject "Quality Control as a Tool of Management." The local chapter of the Society for the Advancement of Management has been invited to participate in this meeting which will be held at Ft. Worth International Airport.

DAYTON The Miami Hotel will be the scene of this section's annual dinner meeting on May 19 with A. L. Davis, president of ASQC, speaking on "Looking Ahead with ASQC."

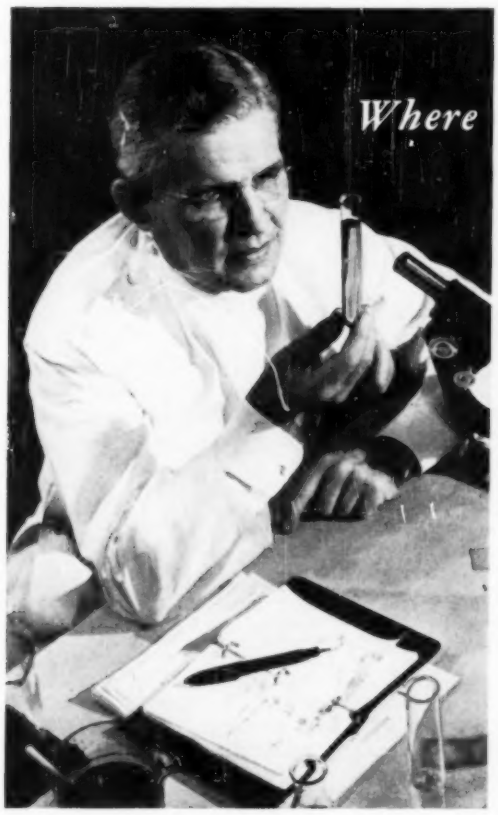
ERIE On May 25 (moved ahead from May 18) a large group is planning to make the 100-mile trek to the Lighting Institute at General Electric's Nela Park in Cleveland. This meeting rings down the curtain on Erie's year except for the Convention.

And now, everyone join in a chorus of "Meet me in St. Looie . . . . Looie!"

LOS ANGELES L. W. Ball, US Naval Test Station, will speak on research and development problems at the May 19 meeting at the Rodger Young Auditorium. At the clinic session Howard Hart, Convair, will conduct a discussion on "Practical Installation of a Quality Control Program in a Large Industrial Plant."

On Friday and Saturday, June 18 and 19 this section will hold a two-day joint meeting with the local chapters of Biometrics and the Institute of Mathematical Statistics. The meeting will be held at California Institute of Technology, Pasadena, with the program on quality control being presented on Saturday afternoon. Among others the program will feature the papers on "Discovery Sampling" by James R. Crawford and "Continuous Variables Sampling Plan" by Harry G. Romig.

LOS ANGELES
San Bernardino Subsection "Quality Rating of Shops and Vendors" will be the subject presented at the June 3 meeting of this group which will



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CALENDAR OF MEETINGS--MAY 20, 1954--JUNE 19, 1954

*Indicates Meeting Dates in May

SECTION	DATE	MEETING PLACE	TIME	SUBJECT	SPEAKER
Albany	1	———	———	Annual Outing & Installation of Officers	———
Allentown-Bethlehem	20*	———	———	How Control Charts are Used at Deere & Co. Plants	E. L. Fay, Deere & Co.
	17	———	———	Panel Discussion "QC and Control Charts"	———
Buffalo	31*	University of Buffalo	———	Film: "Quality Level Certification"	———
Cincinnati	—*	Eng. Society Hq.	8:00	Installation of Officers and Social Meeting	———
Dallas-Ft. Worth	10	———	———	QC as a Tool of Management	A. C. Esenwein, Convair
Dayton	16	———	———	Annual Picnic	———
Denver	25*	———	———	Panel Discussion "The Future of Your QC Program"	———
Erie	25*	———	———	Plant Tour General Electric's Nela Park	———
Kansas City	9	Fairbanks Morse	8:00	Plant Tour	———
Lincoln	18	Capitol Hotel	7:00	Technical Session	———
Los Angeles	18-19	Calif. Tech.	———	Joint meeting with Biometrics & Inst. of Math. Stat.	———
Minnesota	10	———	———	Plant Tour: Ford Motor Co., St. Paul	———
Montreal	2	———	———	Annual Meeting	———
Muncie	28*	Pittenger Student Center	6:30	Quality Level Certification	Robert M. Currie, Ford Motor Co.
Parkersburg	1	Veterans Memorial Park	6:00	Picnic	———
Philadelphia	21*	———	———	Plant Tour: Piasecki Helicopter Corp.	Eric A. Lohmann, Bureau of Aeronautics
Pittsburgh	25*	Sheraton Hotel	6:30	Statistical QC as Applied in a Sand Foundry	Albert J. Kukla, Aluminum Company of America
	15	———	———	Plant Tour: Phoenix Glass Co.	———
Rhode Island	20*	Eng. Society Building	———	A Practical Approach to SQC	Neil B. McLaren, Brown & Sharpe
St. Louis	21*	———	———	Social Evening and Installation of Officers	———
San Diego	14	Inst. of Aeronautical Sc. Bldg.	7:30	Business meeting and movies	———
State Univ. of Iowa	20*	———	———	Dinner and Social Evening	———
Trenton	4	Trenton Tech. Inst.	6:30	Annual Dinner	To be Announced
Utica	20*	Grace Church Parish House	6:30	Acceptance Inspection Program	H. Weingarten, Bureau of Ordnance,
	17	Grace Church Parish House	6:30	To be Announced	W. C. Lee, U. S. Time Corp.
Washington	26*	———	———	Looking Ahead with ASQC	A. L. Davis, Rochester Inst. of Tech.
Worcester	20*	Worcester Polytechnic Inst.	6:00	What Is the QC Job	J. M. Juran, management consultant

be held in Upland. Arrangements for the speaker have not been completed yet.

MUNCIE An increasingly important phase of present quality control programs will be discussed by Robert M. Currie, Ford Motor Co., when he addresses this section May 28 on "Quality Level Certification." The meeting will be held in the Pine Shelf Room of the Pittenger Student Center at 7:30 and will be preceded by a dinner meeting starting an hour earlier.

PHILADELPHIA Our May meeting, the final one until the fall season, will be in the form of a visit to the Piasecki Helicopter Corp. on Friday, May 21. A dinner will be held following the tour and Comdr. Eric A. Lohmann, Bureau of Aeronautics representative, will speak to the group at the dinner meeting.

RHODE ISLAND On May 20, Neil B. McLaren, Brown and Sharpe Mfg. Co., will discuss "A Practical Approach to Statistical Quality Control." The meeting will be held at the Engineering Society Building in Providence.

ST. LOUIS On May 21 the last regular meeting of the year will be held. This will be a social evening and the installation of the new officers for next year.

WORCESTER J. M. Juran, management consultant, is scheduled to talk to the Worcester section on May 20. The meeting will be a dinner meeting and will take place in the Common's Room at Worcester Polytechnic Institute at 6:00 p.m.

"FOR MANY ARE CALLED BUT FEW ARE . . ."

DELAWARE At the meeting on Apr. 1, were announced the results of the election of officers for the 1954-55 season. Chairman: Robert D. Fleck, Continental-Diamond Fibre Co., Newark—Vice Chairman: Robert G. Mitchell, International Latex Co., Dover—Treasurer: Edmund L. Niedzielski, E. I. DuPont de Nemours & Co., Deepwater, N. J.—Secretary: William J. Chelgren, E. I. duPont de Nemours & Co., Wilmington.

ERIE Next years crop of officers in Erie have been determined by a recent election. Chairman will be Dick Herrick, Erie Resistor; vice chairman Paul Hill, Erie Resistor; and secretary Dorothy Kriechbaum, General Electric.

LOS ANGELES
San Bernardino Subsection Officers for the San Bernardino subsection for 1954-55 were elected as follows: chairman, Howard Hart, Convair; vice chairman, Eldon Jory, Norton AFB; treasurer, Allan L. Thompson, Hunter-Douglas; secretary, Gene A. Williams, Kaiser Steel.

ST. LOUIS The new officers of the St. Louis section who will be installed at the May 21 meeting are: president, Rudolph Freedman, Alco Valve Co.; vice president, Waldo A. Vezeau, St. Louis University; secretary, Milton R. Weiss, Alco Valve Co.; treasurer, William Von Meyer, Barry Wehmiller.

TENNESSEE
Memphis Subsection The officers of the newly-formed Memphis subsection are: chairman, Edward P. McMahon; secretary, William Heiskel, Firestone Tire & Rubber Co.; and treasurer, R. L. Coe.

"AS YE SOW . . ."

WESTERN REGIONAL CONFERENCE Arrangements are rapidly nearing completion for the First Annual Western Regional Conference in San Diego, on Aug. 9 and 10. Headquarters for the conference, which is being presented in conjunction with the Aircraft Technical Committee, will be in the U. S. Grant Hotel. An agenda is being set-up which will provide the delegates to the conference with a very interesting technical program, combined with several highlights of entertainment.

Theme of the conference is "Investment Dividends from Modern Quality Control Methods." Arrangements are being made to include in the program speakers who will present factual evidence of "dividends" realized, or which may be expected to be realized through specific, modern quality control methods.

Among the speakers already obtained for the conference are Mayor John D. Butler, of the City of San Diego, Gen. J. T. McNarney, president of Consolidated Vultee Aircraft Corp., J. V. Naish, executive vice president of Consolidated Vultee Aircraft Corp., Dale F. Lobsinger, superintendent of management controls, United Air Lines, Prof. George J. Lieberman, Applied Mathematics and Statistics Laboratory, Stanford University and D. A. Hill, director of quality control, Hughes Aircraft Corp. Other speakers will include leaders in industry, management and government.

In addition, plant tours are being planned for the delegates who desire to extend their stay in San Diego through Aug. 11.

A ladies program has been organized which will include shopping tours, a harbor excursion, floral demonstrations, and a trip to old Mexico.

A visit to picturesque San Diego is a thrilling experience not soon to be forgotten. San Diego's famous zoo and the Cabrillo National Park (most frequently visited of any of the U. S. National Parks) are close at hand. Nearby Mexico, colorful and reminiscent of Old World Spain, with its added lure of jai alai, bull fights and other sports are some of the highlights available.

Naturally, San Diego's ever-present perfect weather may induce many visitors to its numerous beaches or back country. Tours or outings may be arranged to suit the convenience of those in attendance.

SIGNIFICANT DIFFERENCES

The Indianapolis section inaugurated its own Membership Award competition commencing with the March meeting. The membership was randomly divided into a Blue and Red team. Team points will be awarded on attendance at the monthly meetings, obtaining guests for meetings, and sponsoring of new Society members. The prizes, which are six pairs of grandstand tickets for the 1954 Indianapolis 500 Mile Race, will be awarded at our May 18 meeting. Members of the winning team will have four opportunities of winning pairs of tickets and two will be drawn from the losers. Attendence at our Mar. 16 meeting was increased appreciably as a result of this action.

John D. Hinchen, treasurer of Western Massachusetts Section, has introduced a gimmick to encourage more members to attend the dinners. The trick—seasonal dinner passes which results in a $2.00 saving to the member if he attends the dinner before each meeting. As a further encouragement, the passes are transferable.

G. E. Fisher who is vice-chairman of the Eighth National Convention and field engineer for Bell Telephone Laboratories has been called back to the home office in New York. St. Louis also lost during the year another work-horse in John S. Randall who was called to the home office of Chevrolet in Detroit to assist in the setting up a quality control department for the Chevrolet Division of General Motors. Both Gene Fisher and John Randall are past chairmen of the St. Louis section and have always given unlimited effort to the section.

Forthcoming Courses in Statistical Quality Control

PURDUE UNIVERSITY

The eighth annual advanced course in "Quality Control by Statistical Methods" will be held June 14-22. This course is intended for those who have already had an elementary course and who wish to go on to more advanced techniques.

The topics will include significance tests and estimation, acceptance sampling by variables, sequential analysis, linear and multiple correlation, analysis of variance, tolerances of mating parts, and the chi-square test. This course is under the direction of Prof. Irving W. Burr and will include on the instructional staff Profs. Mason E. Wescott, Edwin G. Olds, Lloyd A. Knowler, Cecil C. Craig and Charles R. Hicks.

Further information on the course may be obtained from Prof. Burr at Purdue University, Lafayette, Ind.

MARQUETTE UNIVERSITY

The Marquette Management Center is presenting, in connection with the Milwaukee section of ASQC, a short course on "Introduction of Quality Control by Statistical Methods," June 14-25, 1954 at the Marquette Management Center.

The course will be under the supervision of Dr. M. E. Mundel, associate director of the Management Center and it will be taught by a group of three instructors: Gayle McElrath, of the University of Minnesota, Harmon S. Bayer, quality control consultant from Detroit, Mich. and Joseph Movshin, production quality manager of the Mansey Corp., St. Louis. Guest speakers for the course will be R. S. Saddoris, and L. S. Eichelberger, A. O. Smith Corp.; I. W. Schoeninger, Globe

Union; A. E. Jakel; H. Gulde, Minneapolis-Honeywell; and Prof. J. MacKenzie, University of Minnesota.

The program is designed for those in industry who desire a basic course in statistical quality control. The program will be directed at a realistic approach through the presentation of the practical basic concepts together with integrated and specialized workshop sessions to insure each enrollee of adequate instruction. The aim will be to prepare each enrollee to organize, administer, and to apply SQC techniques in his own work situation.

Enrollment will be limited to approximately 60 persons. The cost of this course will be $100 (housing at the enrollee's expense). For further information contact the Management Center, College of Business Administration, Marquette University, Milwaukee 3, Wis.

UNIVERSITY OF MICHIGAN

The University of Michigan has scheduled the seventh annual presentation of its ten-day intensive course in statistical quality control for Aug. 16-26, 1954, on the campus in Ann Arbor. This is a first course for executives and supervisory personnel; it is practical and mathematically non-technical. It includes the standard control charts and sampling acceptance plans together with other basic techniques.

Instruction includes lectures, demonstrations, practice sessions, and conferences. The same experienced staff will be in charge of the course. The fee will be $100.

Please address inquiries to the course director, Prof. C. C. Craig, 106 Rackham Building, Ann Arbor, Michigan.

FIFTH "HORSE'S MOUTH" COURSE

For the past four years, the New England sections of ASQC and the University of Connecticut have presented a Statistical Quality Control Institute which is now well known as the "Horse's Mouth" course. This course is unique in its presentation in that it is basic, rather than elementary or advanced. It is a survey of the available techniques and their applications in industry. It is not a classroom presentation with an academic approach, but rather a dynamic exchange of ideas with some of the leading men in the quality control field.

The concepts emphasized in the Institute deal with the basic applications of statistical quality control in inspection, production, engineering and purchasing. This allows the registrant a broad look at the entire quality control picture as it exists today, and a look into the future of this evergrowing field. The number of registrants is limited to 60 in order that individual attention can be given to the problems brought in by the registrants.

Staff will again consist of nationally known people in the quality control field. Material will include detailed descriptions of the most recently developed practical techniques such as binomial probability paper, lot plot, continuous lot plot, and reset-run cards.

Registration fee is $160 per person and includes room, board, and text and class materials. A get-acquainted party opens the Institute Sunday evening, Sept. 12th, and certificates are awarded Friday noon, Sept. 24th.

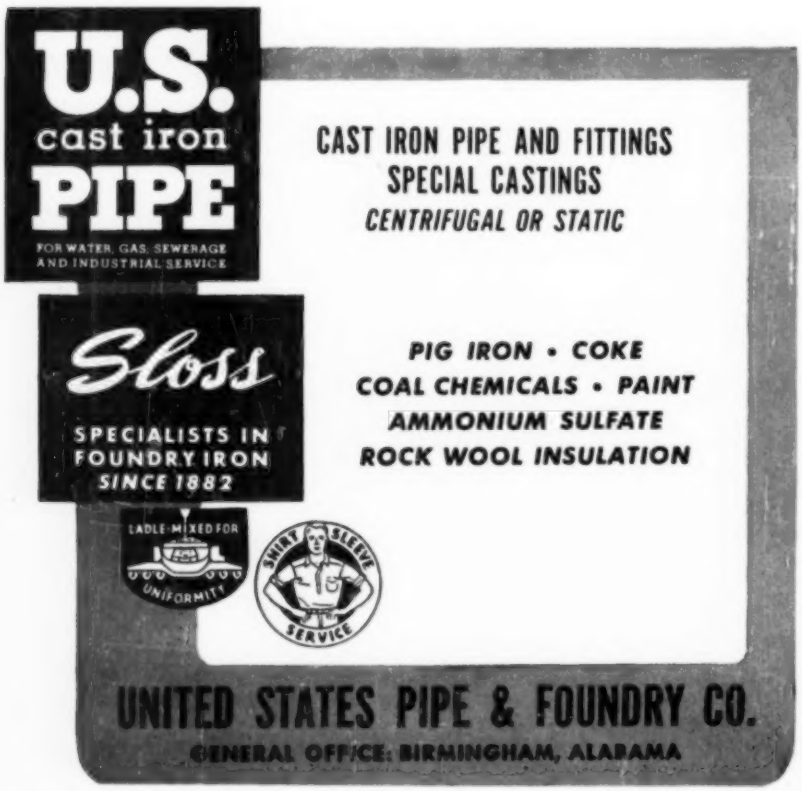
For further information or registration, write to R. M. Story, Jr., Coordinator, SQC Institute, Box U-41, University of Connecticut, Storrs, Conn.

RUTGERS UNIVERSITY

An eight-day, Advanced Course in Quality Control by Statistical Methods will be offered by Rutgers University at Newark, New Jersey, Sept. 8-12, 1954. This will be an intensive course running for eight consecutive days (Sunday excluded) instead of one day a week for 10 weeks as has been the practice in the Rutgers Basic Conference Series.

The course is designed to provide additional instruction for persons who have had a basic course and industrial experience in the SQC field. It will include advanced topics in SQC such as sampling by variables, sequential analysis (both attributes and measurements), narrow-limit gaging, significance of differences, tolerance combinations, simple and multiple regression and correlation, chi-square, basic experimental design, analysis of variance, and the organization and management of a quality control program.

Tuition is $150, which includes text and instructional material. For additional information write to Prof. Ellis R. Ott or Mason E. Wescott, University College, Rutgers University, New Brunswick, New Jersey.



STATE UNIVERSITY OF IOWA

A ten-day intensive training course in Quality Control by Statistical Methods will be offered by the State University of Iowa at Iowa City, Oct. 19-29, 1954. This will be an introductory course which will follow the same general pattern of previous basic courses.

Instruction will be by lecture, demonstration, laboratory work, and evening question and problem discussion sessions, with the emphasis on practical interpretation throughout.

The tuition of $100 per person includes all necessary instructional materials. Room accommodations will be available at the Jefferson Hotel in Iowa City. Make room reservations directly with the hotel.

Further inquiries concerning this course should be addressed to Professor Lloyd A. Knowler, Chairman, Department of Mathematics, The State University of Iowa, Iowa City.

9TH SQC COURSE FOR THE CHEMICAL INDUSTRIES

An eight-day intensive training course in quality control for the chemical industries will be offered by the Rochester Institute of Technology at Rochester, N. Y., Oct. 12-20, 1954. In contrast to courses which usually emphasize mechanical and metal cutting operations, the content of this program is devoted exclusively to the control problems of the chemical and allied process industries.

The course is particularly designed for those responsible for controlling product either in the analytical laboratory or directly in the manufacturing process. Emphasis will be placed on the practical application of quality control in these areas. Instruction will cover basic statistical control and sampling methods as well as many of the advanced techniques such as design of experiments, correlation, and analysis of variance. Companies engaged in research and development work, or those having a continuous or batch-lot type of production process will find the program of particular value.

The tuition of $100 per person includes books and supplies. Room accommodations will be available at the Hotel Rochester. Further inquiries should be addressed to the course coordinator, Robert D. Pease, Evening Division, Rochester Institute of Technology, Rochester, N. Y.

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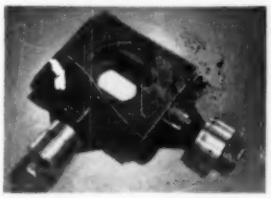

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American Society News

EXECUTIVE COMMITTEE MEETING

The Operating and Executive Committees of the Society met Feb. 16 and 17, 1954. The Rochester section played host, the two meetings being held during and following its Tenth Annual Clinic — the all-day series of sessions that have become a tradition in the area.

Approved, subject to compliance with some last-minute technical details, was the admission of the 76th section to the Society.

76 Albuquerque (NM)

Chairman: Aldis S. Hayes

Vice Chairman: Arvin F. Cone

Secretary: J. M. Gustafson

Treasurer: Daniel D. Sheldon

Membership is fast approaching the 8,000 mark. This year's total is now the highest in the Society's history:

	Renewing Members	*New Members*	*Total*
1954	5611	2160	7771
1953	4466	2287	6753

Both sets of figures are as of Feb. 28.

In preparation for the first Presidential Award for Section Management, the design of a plaque and a banner for the winning section were approved. The presentation will be made at the Eighth Annual Convention in St. Louis.

This year it has been the policy of the Operating Committee at its meetings to hear and discuss in person, a report from a chairman of a Society committee. At this meeting Frank Caplan reviewed the work of his Publicity Committee. At previous meetings Harmon Bayer reported on his Membership Committee and Leonard Seder on his Program and Speakers Committee. The exchange of information has been most valuable.

The Technical Divisions of the Society, it has been reported, are setting up editorial boards to preview papers in their area for submission to the Society Editorial Board for possible publication in IQC. Also a five-point proposal to help finance division activities was approved.

It is planned, in St. Louis in June, to set up subcommittees of the new Technical Committee on the subject of business operations. It is expected that this group will be known as the "Administrative Applications Committee," according to a report by Dale L. Lobsinger. Five papers at the Convention will be on aspects of this work.

The Executive Committee approved the recommendation of the Committee to Study Society Dues Structure that Fellow grade dues be the same as Senior grade dues. A constitutional amendment, to be voted on by the Society's members, is now being prepared.

Society aid was approved for a joint regional and aircraft technical committee conference. The first

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conference of the Western Region is planned for Aug. 9 and 10, 1954, in San Diego, Calif. Its theme is "Investment Dividends from Modern Quality Control Methods."

COMMITTEE CHANGES

William E. Spencer has been appointed to the Film Library Committee.

William P. Schwager was appointed to the Constitution and By-laws Committee to replace John H. Howell, resigned.

W. Edwards Deming was appointed to the Standards Committee to replace A. E. R. Westman, resigned.

FELLOWS

On the recommendation of the Examining Committee, the following members have been elected to Fellow Grade.

Rudolph Freedman
Alco Valve Company
St. Louis, Mo.

Miriam S. Harold
Bell Telephone Laboratories
Murray Hill, N. J.

Joseph Movshin
U. S. Air Force
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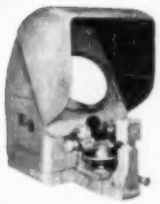

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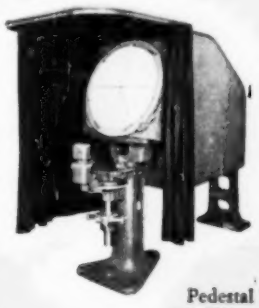

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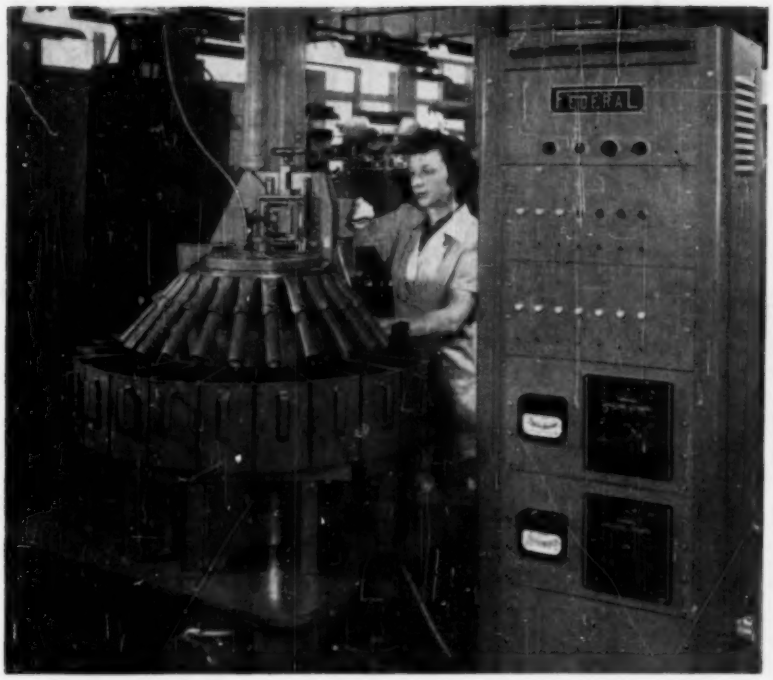

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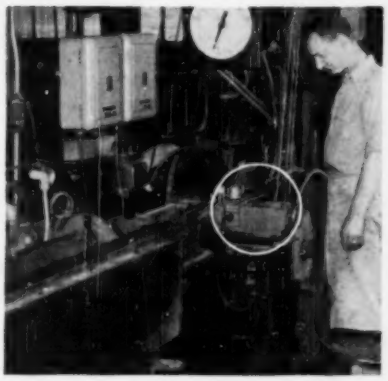

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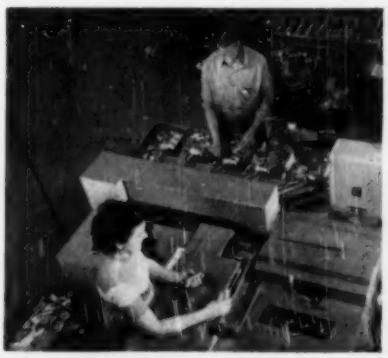

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